THE HISTORY OF ATTIC VENTILATION REGULATION AND RESEARCH

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ABSTRACT

The aim of this paper is to review the research literature and regulatory documents on attic ventilation in the United States. Before, during, and immediately following World War II there was a spurt of regulatory and research activity that gave rise to the current standards and guidelines that govern residential construction practice. Upon review of the literature of that time, it becomes apparent that the findings of the research are not consistent with the conclusions drawn by researchers and others. In particular, the rule requiring an attic ventilation ratio of 1:300 does not appear to have been justified at the time of its promulgation. The research that was intended to substantiate the rule fails to support it. The promulgation of the 1:300 rule went forward, nevertheless.

A second spurt of interest in attic performance began in 1978, with several research papers tending toward the conclusion that ventilation of well-insulated attics does not have a significant effect on cooling load. Monitoring efforts in the 1980s showed that air leakage and moisture storage are the predominant determinants of performance. Modeling efforts showed greater success with temperature prediction than with moisture prediction.

INTRODUCTION

Purpose

The aim of this paper is to present the sources of regulations governing attic construction, particularly attic ventilation. The focus of the search has been in the 1940s in the United States, when the well-known 1:300 venting ratio first appeared in documents of the Federal Housing Authority (FHA). This article presents the results of a literature search and review of previous research reports. Documents at a U.S. university and at the U.S. Department of Housing and Urban Development (HUD) have been scoured for references to attic ventilation. The search was intended to be exhaustive. The findings are presented here and conclusions are drawn from a critical reading of the articles that were available.

Conclusions also are drawn from the *absence* of material, particularly the absence of material that would substantiate the regulatory documents. Of course, this method is subject to criticism whenever relevant documents that may have been ignored are brought to light. Readers and reviewers are invited to continue the work begun here by presenting other relevant work, and the conclusion presented here may have to be modified by future presentations.

It is the opinion of this author that research of high quality should be used for the improvement of building regulation and practice. However, regulations and construction decisions must often be made in the absence of applicable research, as was the case following World War II. In this paper, there is no intent to criticize the formulators of building regulations for failure to correctly anticipate later findings. Indeed, they often seemed to exhibit excellent judgment.

This paper does *not* aim to address whether or not attic ventilation is an appropriate construction practice.

Early Construction Methods

Traditional construction has been documented in many works and can be found in many examples of preserved buildings. In traditional construction, roofs were never airtight. Rather, the building itself often acted as a chimney. Holes in roofs were a part of all primitive construction, as has been noted by Mircea Eliade, a historian of religions (Eliade 1957). Most indigenous pre-industrial buildings, at least outside of the Mediterranean area, were steep roof structures. In agricultural buildings, a cupola was added to ensure that the moisture and odors generated within could easily and safely exhaust to the outside. Industrial buildings had vented roofs to prevent the buildup of smoke or other pollutants. Much early fire prevention hinged on holes high in the roof, which lessened the likelihood of horizontal fire spread.

Through the nineteenth century, roofing materials (slate or tile on lath) were porous to air movement, thus providing natural ventilation of attic spaces. Thus, the roofing, support, and framing materials all tended to

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be in equilibrium with the outdoors, even as humidity generated indoors passed by these materials on their way out of the building. Natural roof ventilation tended to prevent the buildup of humidity or smoke within the interior of the building because there was a continuous flow of indoor air upward and out of the building.

The first major technical change occurred with the introduction of bituminous roofing materials, first in low-slope roofing and later in steep-roof construction (shingles). These nonrigid materials required continuous sheathing or decking. A bituminous roof/deck was impermeable to the movement of moisture, and this construction introduced concerns for the buildup of condensation. Pamphlets from the 1930s show concern by painters regarding paint peeling from "poorly vented" gables. However, it is worthy of note that documents from the 1920s and 1930s, for example, FHA 1935, while stressing concern for moisture problems in foundation spaces, apparently considered steep-roof residential construction with continuous board sheathing to be free of moisture problems.

The second technical change that occurred was the introduction of plywood into residential construction during and after World War II. Plywood was found to be more subject to deterioration than board sheathing. With its introduction, the first concerns for rotting sheathing began to be expressed. One of the early researchers, Britton, found that rotting plywood sheathing occurred in buildings with wet foundation areas (Britton 1949a).

A third technical change was the expanded use of cathedral ceilings. Story-and-a-half construction, where a section of the upper story has a sloped ceiling between the knee wall and the ceiling, was common even in the 1800s. With panelization and modularization of residential construction in the 1950s came much greater use of cathedral ceilings as design elements or as elements that simplified transport and site erection.

A fourth technical change was the increase in insulation levels, which occurred with the beginning of the century, but expanded greatly during the oil crises of the 1970s.

Performance Models and Analysis

To better understand attic construction regulations, it may be helpful to try to render as explicit as possible the implicit assumptions and hypotheses that underlie these regulations. Three distinct models of how attics perform can be seen in tracing the history of attics and attic ventilation.

- The earliest attics followed the traditional or agricultural model, in which attic openings served to intentionally ventilate the entire building. This paradigm lies behind the expression, "A building has to breathe."
- In "modern" construction, an airtight ceiling (in principle) prevents flows from the interior to the attic. This paradigm is found in any analysis that accounts for diffusion. Diffusion has been shown to be a significant transport mechanism only in the absence of air movement by convection.
- The most realistic model is a "mixed" model, in which the attic spaces or cathedral ceiling cavities are variously attached to or detached from air volumes below. Pathways for connection include chases for plumbing, ductwork, flues, and electrical wiring.

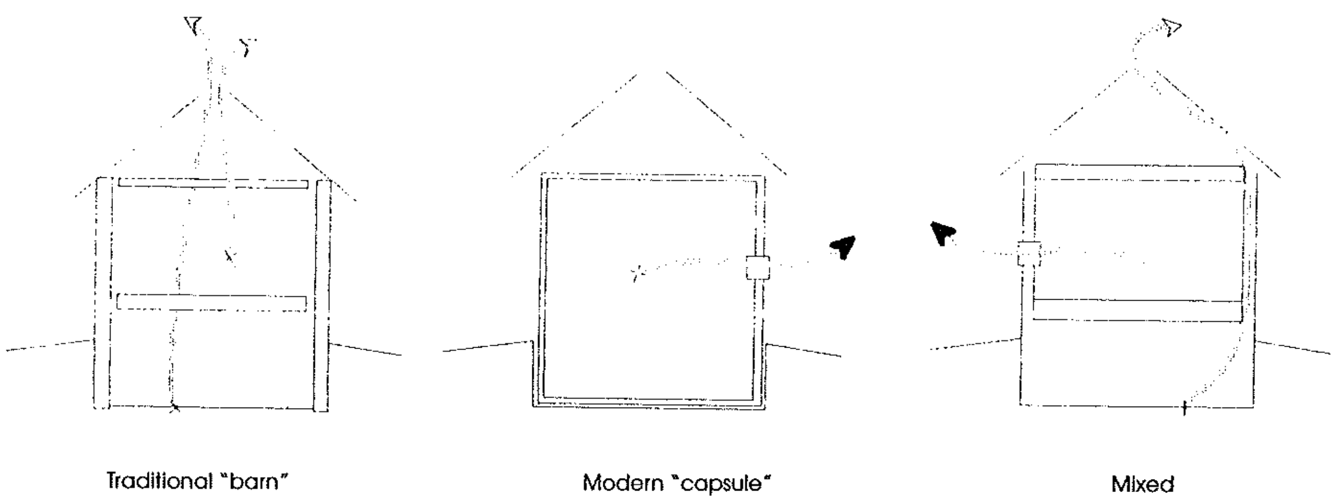

Figure 1 Three models of residential construction, with their impact on attic performance. In traditional construction (including agricultural construction), the attic acts as a chimney to discharge moisture from the foundation and from interior uses. In modern construction, the living space receives little moisture from the foundation and all moisture discharge is independent of the attic space. In mixed construction, the attic serves as the outlet for foundation moisture, while interior moisture may be discharged directly outside.

Certain other assumptions that are commonly found in the literature should be made explicit. These include:

- Winter conditions are more critical than summer conditions; northern regulations should be imposed broadly across the United States.
- The interior is "humid," although there have been no guidelines for indoor humidity. There is no concept of "moisture load" to correspond to live and dead loads for structural analysis. Assemblies have presumably been designed to withstand any possible moisture load.
- Many moisture control options are acknowledged, such as vapor barriers, ceiling airtightness, and ventilation, but ventilation is, by far, the most closely watched and regulated.
- No performance criteria are set, but sheathing deterioration (both mechanical and microbiological) is undesirable.

RESEARCH AND REGULATION

Rowley

In 1938 and 1939, Frank Rowley conducted wall and attic research at a U.S. university, and the results were published in *ASHVE Transactions* (Rowley et al. 1939). His aim was to test the resistance of various wall and roof assemblies to the accumulation of condensation under steady-state conditions. In an insulated test room he built three small test huts, shown in Figure 2. One hut had no ventilation, a second had mechanical ventilation, and a third hut had natural ventilation. Small aluminum panels were placed at the sheathing to collect frost. The panels were removed and weighed and any change in weight was attributed to frost accumulation on the panel. The ceiling was plaster on metal lath and appears to have been airtight. No vapor barriers were used, so all moisture transfer can be assumed to have been via diffusion.

The outset of his test, "period 2-3," contained the most difficult climatic conditions, with low "outdoor" temperatures (−10°F [−23°C]) and an indoor humidity of 40%. The hut with no ventilation showed an accumulation of moisture that ceased once the outdoor air temperature was elevated to 15°F (−9°C). The hut with natural ventilation showed no accumulation with a 1/4-in.^{2} opening for each square foot of ceiling area (1:576 ratio), but condensation appeared once the opening area was reduced by half (1:1152 ratio). The hut with mechanical ventilation showed no condensation at 3 ft^3 per hour per square foot of ceiling area (1 m^3 per m^2), but a trace of condensation appeared when the ventilation flow rate was cut in half. Rowley stated, "Evidently test period number 2-3 represents the minimum of ventilation for either natural or mechanical ventilated attic."

Rowley drew conclusions about both walls and attics. With regard to attics, Rowley concluded:

> 4. It is possible to reduce the rate of condensation within the structure by ventilating to the outside. This method may be particularly effective in attics where the condensation occurs on the underside of the roof. Adequate ventilation may be obtained without serious loss of heat...
>
> 9. For cold attic spaces it is desirable to allow openings for outside air circulation through attic space as a precaution against condensation on the underside of the roof even though barriers are used in the ceiling below.

Conclusion number 4 makes sense, and is a valid deduction from the experiment. A large vapor pressure difference was established across a plaster ceiling with no vapor barrier. Without dilution, sheathing condensation would be simple to predict by the dew-point method.

However, the paper contains no basis for conclusion No. 9. Rowley reported on no tests that included ceiling vapor barriers. The wall tests reported in this article showed decreases in the amount of condensation in wall sheathing due to the use of a vapor barrier to be from a 10× decrease to a 100× decrease, to the elimination of all condensation. Thus, it is difficult to imagine what Rowley's estimate of attic sheathing condensation would be, or how he could argue that his ventilation findings could apply to the case of a ceiling with a vapor barrier.

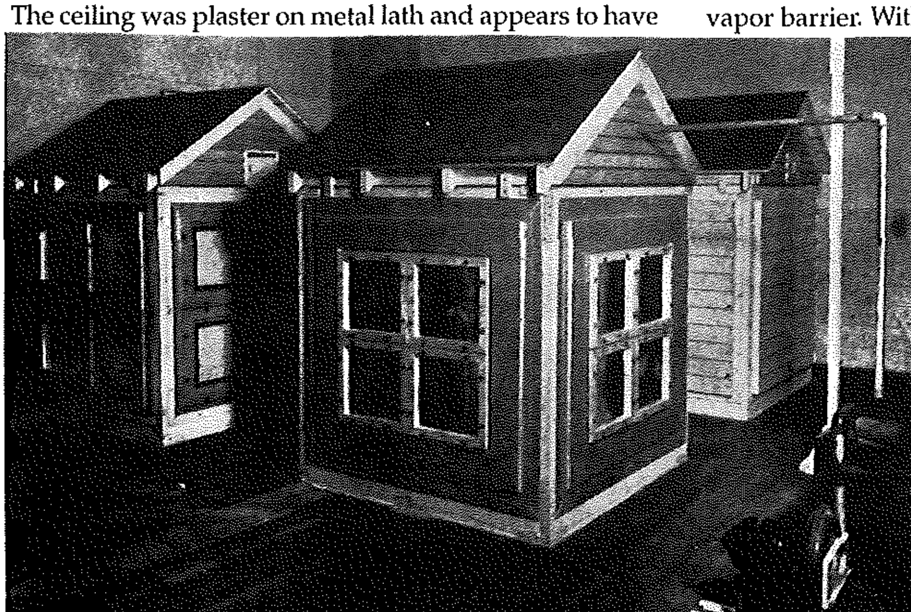

Figure 2 Setup of test cells under Frank Rowley.

FHA Property Standards 1942

In January 1942 there appeared "Property Standards and Minimum Construction Requirements for Dwellings," published by the National Housing Agency for the FHA (FHA 1942). It contains substantial revisions from all of the previous "Property Standards" forms published by the FHA for use by state and regional offices. It contains this requirement:

> 209K Attics (Includes air space between ceiling and flat roofs).
>
> 1. Provide effective fixed ventilation in all spaces between roofs and top floor ceilings, by screened louvres or by other means acceptable to the Chief Architect.
> 2. Net ventilation area for each separate space to be not less than 1/300 of horizontally projected roof area. Where possible, locate vents to provide effective cross-ventilation.
> 3. Use corrosion-resistant screening over openings, mesh not less than 12/in.

This is the first statement of the requirement for 1:300 ventilation. It appeared in January 1942 with no explanation or attribution. It does not appear to be based on Rowley's work for two reasons: (a) later FHA (HHFA) researchers claimed to be unfamiliar with any precedents (see below), and (b) in a later publication (Rowley 1947), Rowley argued for a vent ratio of 1/4 in.^{2} per ft^2 of ceiling area, or 1:576, a number that he was able to justify from his own research results. Thus there is no explicit rationale given for the 1:300 rule, and the one available reference for attic condensation, Rowley, does not appear to have been taken into account. It is interesting to note that the first requirement for the ventilation of crawl spaces appeared on the same page of the same document (Rose 1994).

Ralph Britton

Following World War II, the National Housing Agency was converted to the Housing and Home Finance Agency (HHFA). In January 1947, Ralph R. Britton, a structural and architectural engineering adviser on the technical staff of the HHFA, undertook a series of tests on walls and roof-ceiling assemblies (Britton 1948). The research took place in a climatometer that had recently been put into service. The climatometer was capable of maintaining uniform cold and hot temperatures. The results of the wall and roof-ceiling tests are reported in HHFA Technical Bulletins 1, 2, 3, 8, and 12. The roof-ceiling work is reported only in Technical Bulletins 1 and 2; the wall research continued in the later reports.

The report begins with a curious remark under "Test Procedure": "When this program started there was, to the best of our knowledge, no past experience to serve as a guide in setting up a test procedure." The researchers appear to have been unaware of Rowley's work. The aim of the tests was expressed on the first page: "The tests are designed to provide needed technical data on the performance of new materials and new methods of assembling old and new materials in construction suitable for use in obtaining structurally adequate, durable and livable dwellings."

Six test roof-ceiling panels were constructed and placed on a building made up of the test wall panels. The entire "building" fit tightly within the climatometer, as shown in Figure 3. This figure contains a sketch of the ventilation slots in the eaves. It may be important to note the differences between the test conditions and common field conditions:

- The test was steady-state for one- or two-week periods at cold temperatures.
- There was no provision for radiant effects, either sun or nighttime cooling.
- The roofs were flat.

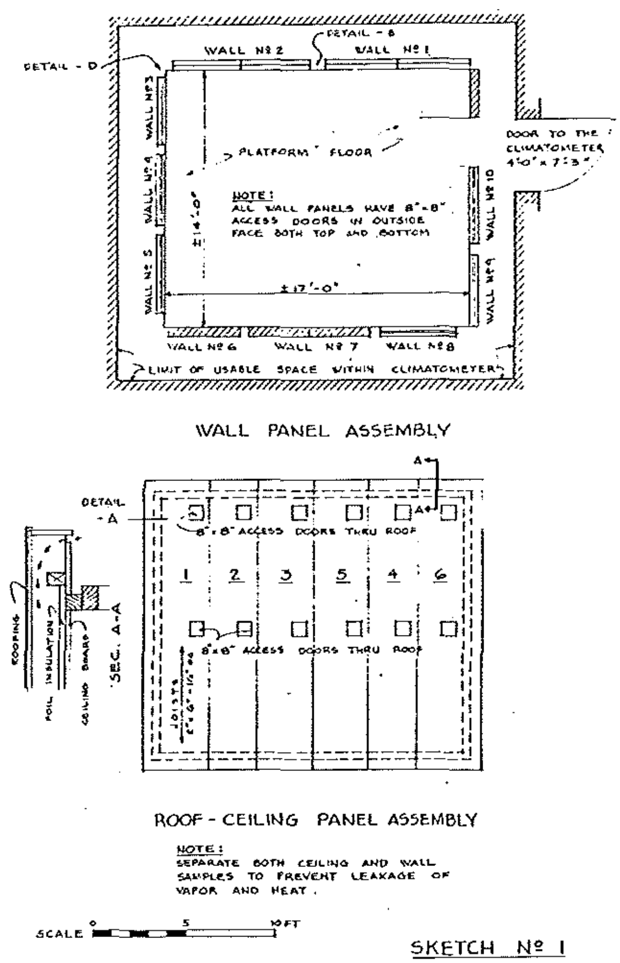

Figure 3 *Plan and section of test panels from Britton's research.*

TABLE 1

Case	Vapor Barrier	Insulation or Radiant Foil	Ventilation	First Finding, March 5	Second Finding,	Conclusion
1	vb, cont.	rock wool	1/300	ok	ok	ok
2	vb, facing	rock wool	1/300	ok	ok	ok
3	no vb	rock wool	1/300	frost	frost	visual[a]
4	no vb	refl. foil in mid	1/300-none[b]	cond.	cond.	visual
5	no vb	refl. foil near top	none	cond.	ice	visual
6	no vb	2 refl. foils	1/300-none	cond.	water	visual
1a	as in 1	as in 1	none	some frost	ok	ok
2a	as in 2	facing unstapled	1/300	ok	ok	psych.[c]
3a	as in 3	as in 3	1/100	ok	slight moist.	psych.
7	no vb	2 refl. foils	none	frost	ok	ok
8	no vb	2 refl. foils	none	water, mist	cond. at edge	ok
9	no vb	3 refl. foils	none	drops	not insp.	ok

[a] "Visual" means that there was visual evidence of condensation.
[b] Ventilation of 1/300 was closed before inspections were conducted.
[c] "Psych." means that, although there was no visual evidence of condensation, the psychrometric conditions indicated that condensation was imminent.

- There were inspection hatches through the roof side of each test panel.
- There is no mention of openings in the ceiling in the project description (though curiously the "findings" section mentions that photographs of sheathing conditions were taken from below).
- The ceiling material was "1/2 in. structural insulating board."
- The research report gives no idea of how air pressures might have played a role.

There were two phases, with six different roof assemblies in each phase. The 12 cases studied are shown in Table 1. Phase I (cases 1 through 6) lasted from January 28, 1947, to March 6, 1947, and is written up in Technical Report No. 1. Phase II (cases 1a, 2a, 3a, 7, 8, and 9) lasted from March 27 to May 7.

In phase I, there is a description of roof No. 1. This roof is of particular interest because it is the insulated roof studied both with and without ventilation. The roof had

- granular-surfaced roofing,
- 5/16-in. Douglas fir plywood,
- 2-in. air space,
- 4-in. rock wool insulation,
- kraft paper facing with two aluminum foil faces,
- 1/2-in. structural insulation board,
- one coat flat paint,
- joists 2 by 6—16-in. o.c.,
- cold-side ventilation 1:300, and
- excellent workmanship in applying barrier.

Roof 2 was like roof 1 except that the vapor barrier was a simple kraft facing. Roof 3 was similar, but with no vapor barrier at all. Roofs 4, 5, and 6 had only single sheets of reflective foil and had no mineral wool insulation at all. They were ventilated at 1:300.

In Phase II:

- The cold-side ventilation of roof 1 was closed completely. Roof 1 became roof 1a.
- The attachment of the kraft facing in roof 2 was modified, and it became roof-ceiling 2a.
- The ventilation in roof-ceiling 3 was enlarged from 1:300 to 1:100 (roof-ceiling 3a).
- Roofs 4, 5, and 6 were modified to have double sheets of reflective foil but still no mineral wool insulation and the vents were closed. They became roof-ceilings 7, 8, and 9.

So the vented assemblies were roof-ceilings 1, 2, 3, 4, 5, 6, 2a, and 3a. The unvented assemblies were 1a, 7, 8, and 9.

Beginning January 28, the cold "outdoor" conditions were varied from 20°F (−7°C) to 0°F (−18°C). The interior temperature was 70°F (21°C) and the indoor relative humidity (RH) was varied from 46% to 38%. Through several steps, no problems were encountered in roof-ceiling 1. Then the ventilation was closed completely and an inspection took place on April 18. Here are the findings for roof-ceiling 1a, which show that the researchers knew of the importance of air leakage:

> No evidence of condensation was found in the cold cavity at the center access door. At the access door near the edge a small amount of frost was found on the inside of the door, the bolt attaching the handle of the door, the nails extending through the plywood sheathing, and around the edge of the door.
>
> It is quite possible that some of this was caused by vapor gaining access to the cavity through a hole drilled for instrumentation. Close inspection indicated a not too effective attempt at sealing this hole.

On April 25, a new series was begun with the same temperature and humidity conditions as in the previous test. On May 7, an inspection took place, with these results for roof-ceiling 1: "No trouble. The slight amount of moisture noted in the cold side of the cavity at the edge access door was no doubt due to a small hole through inside surface for instrumentation."

At the end of Technical Report No. 2, several conclusions were drawn. Regarding the roof-ceiling results, Britton concluded:

> 4. Based on visual inspection only, the following wall and roof-ceiling constructions may well be questioned for suitability for the most severe parts of the United States: Walls 2, 12, and 13. Roof ceiling 3, 4, 5, and 6.
>
> 5. Based on a study of psychrometric data with reasonable allowance for variable state conditions being more severe than steady state conditions of testing, the following wall and roof-ceiling constructions may well be questioned for suitability for the most severe parts of the United States: Walls, 1, 1a, 2a, 5a, 7, 7a, 10a, 12, and 13. Roof-ceilings 2a and 3a.

These are the final conclusions from the entire HHFA study regarding roof-ceiling assemblies. Regarding the cases with mineral wool insulation (ignoring the reflective foil cases): The suitable roof assemblies were roof-ceilings 1 and 2 (with well-installed vapor barriers and 1:300 ventilation) and 1a, with no ventilation. The questionable roof-ceiling samples were 3, 2a, and 3a, all vented assemblies. Clearly, one cannot conclude from these research results that ventilation provides sufficient moisture control for roof-ceiling assemblies. The effectiveness of a vapor barrier was demonstrated. The research also highlighted the importance of sealing air leakage paths, but the researchers appeared unable to incorporate their findings about air leakage into their conclusions. (It is to their credit that their observations were complete enough that future researchers could review their data for factors such as air leakage, which were not part of the original intent.)

Another important paper by Ralph Britton was "Crawl Spaces: Their Effect on Dwellings—An Analysis of Causes and Results—Suggested Good Practice Requirements" (Britton 1949a). In it, Britton identified wet crawl spaces as the principal cause of deterioration of attic sheathing in a case study of 72 apartment buildings with low-slope roof systems, shown in Figure 4. He identified the path that moisture takes in going from the crawl space to the attic, and he showed that it bypasses the living space. He showed that by changing the kind of attic ventilation from exhaust-only to inlet-plus-exhaust, crawl-space moisture would rise but attic sheathing moisture would go down. He also recommended that, if workmanship were sufficient to ensure that crawl-space moisture did not leak into the attic space, then the attic ventilation ratio could be reduced by 90% (from 1:300 to 1:3000, it may be presumed).

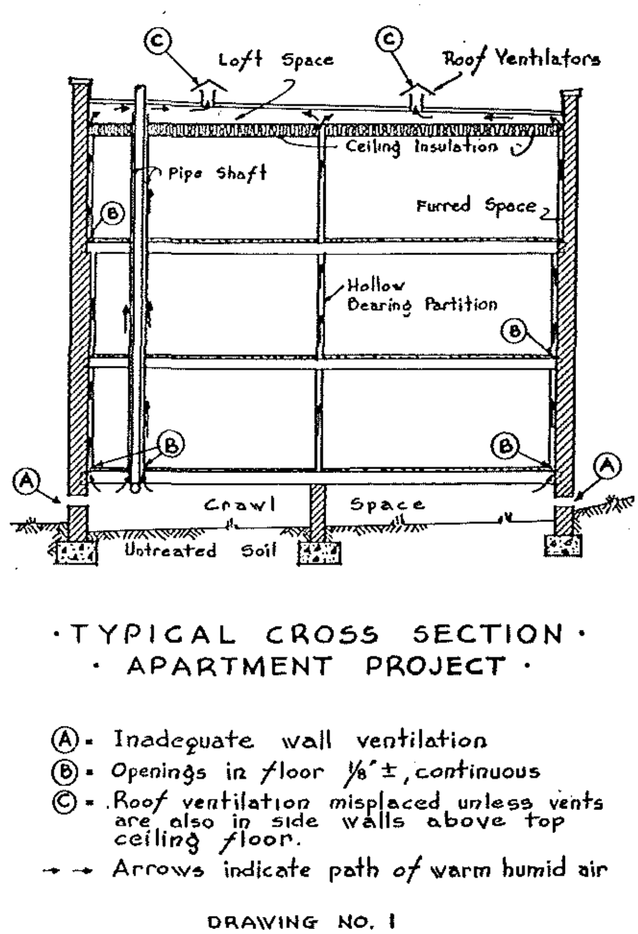

Figure 4 Section of case study apartment building from Britton (1949), showing the path taken by humid air from the wet crawl space, through the furred spaces, up to the loft or attic space.

> Note: Where an effective vapor barrier is assured in the top-story ceiling, loft or attic space ventilation specified above may be greatly decreased. Such a decrease may be as much as 90% where controlled construction is assured and walls or crawl space do not contribute to moisture supply in the attic or loft space.

This conclusion is important because it indicates the thinking by Britton and presumably the HHFA. It highlights the importance attached to moisture loads from the foundation. It allows speculation that the attic venting ratios might have been different had there not been Britton's experience with wet crawl spaces.

Britton wrapped the conclusions from his wall/roof studies and his crawl space investigations into an im-

Table 1.—*Recommended good practice—loft and attic ventilation*[1]

Type of roof and occupancy	Condensation zone I	Condensation zone II	Condensation zone III
(a) Flat roof—Slope less than 3 inches in 12 inches. No occupancy contemplated.	Total net area of ventilation should be 1/300th[2] distributed uniformly at the eaves *plus* a vapor barrier in the top story ceiling. Free circulation must be provided through all spaces.	Same as for zone I..............	Same as for zone I.
(b) Gable roof—Slope over 3 inches in 12 inches. No occupancy contemplated.	Total net area of at least 2 louvers on opposite sides located near the ridge to be 1/300th[2] *plus* a vapor barrier in the top story ceiling.	Same ventilation as for zone I. A vapor barrier is not considered necessary.	Same as for zone II.
(c) Hip roof—No occupancy contemplated	Total net area of ventilation should be 1/300th[2] with 1/600th[2] distributed uniformly at the eaves and 1/600th[2] located at the ridge with all spaces interconnected. A vapor barrier should also be used in the top story ceiling.	Same ventilation as for zone I. A vapor barrier is not considered necessary.	Same as for zone II.
(d) Gable or hip roof—With occupancy contemplated.	Total net area of ventilation should be 1/300th[2] with 1/600th[2] distributed uniformly at the eaves *and* 1/600th[2] located at the ridge with all spaces interconnected. A vapor barrier should also be used on the warm side of the top full story ceiling, the dwarf walls, the sloping part of the roof, and the attic story ceiling.	Same as for zone I..............	Same as for zone I except that a vapor barrier is not considered necessary if insulation is omitted.

[1]It is recognized that in many areas increased ventilation may be desirable for summer comfort.
[2]Refers to area enclosed within the building lines at the eave level.

Figure 5 *Table of recommended good practice—loft and attic ventilation, as it appeared in Britton "Condensation Control in Dwelling Construction: good Practice Recommendations" and HHFA "Condensation Control in Modern Buildings."*

portant article (Britton 1949b). Here his research results led to "recommended good practice," which took the form of a table, shown here as Figure 5.

Jordan et al./FPL

In 1948, another series of three tests were conducted by Jordan et al. (in conjunction with the Housing and Home Finance Agency) (Jordan et al. 1948).

Their first test was to compare air velocity through a louvered opening with no obstruction against air velocity through the same opening with 16-mesh wire screen. They found that at high velocities (more than 100 fpm [30 m/min]), the screen reduced air movement by 20% to 25%. At low velocity, the screen reduced the air velocity by almost 400%, from 114 fpm (35 m/min) to 36 fpm (11 m/min). The authors concluded that such a screen would probably block off all air movement induced by temperature difference.

As a second test, they studied three occupied houses in Madison, Wis., from mid-January through February 1947. Gravimetric weighing of wood slivers was used to determine moisture content. The moisture content indicated attic relative humidity. They found that only one house had a high moisture content and it was the house with high indoor humidity. They concluded that attic moisture is more a function of indoor humidity than of vapor barriers or ventilation.

Their third test was for condensation under controlled laboratory conditions. A small test chamber was outfitted to indoor, outdoor, and attic conditions. Mechanical ventilation was provided between 0.6 air changes per hour (ACH) and 1.5 ACH. (Later research by Forest and Walker [1993] showed air change rates in test attics from 1 to 10 ACH.) The results showed frost formation in most of the unventilated cases and dissipation of the frost in most of the ventilated cases. The authors found frost even in the case where an asphalt vapor barrier was installed, leading to the conclusion that attic ventilation is desirable even with a vapor barrier. The authors came to the following conclusion,

> The considerable lowering of attic temperatures caused when insulation was placed in the ceiling panel did not increase the formation of frost materially. When insulation was used, however, the amount of ventilation necessary to prevent or remove frost had to be greatly increased. This was due to the fact that the lower attic temperatures prevailing when the ceiling was insulated necessitated removal of much more air to get rid of a given quantity of moisture vapor, because a given volume of the colder air holds less vapor.

The authors indicated that ventilation rates much higher than those provided by the 1:300 ratio may be necessary in "highly insulated attics," i.e., attics with more than 4 in. (10 cm) of insulation.

HHFA "Condensation Control in Modern Buildings"

In August 1949, "Condensation Control in Modern Buildings" appeared. This publication (HHFA 1949) was the pivotal publication that served as the basis for almost all future standards and regulations. It synthesized the previous research and recommended practices, particularly that of Britton and Jordan. It replicated the table from Britton (1949a), shown here as Figure 5.

Hutcheon and Air Leakage

Britton, in his article cited above (1949a), had illustrated the damaging effects of airflow from wet crawl spaces into attics, but the outcome of his work was a focus on diffusion and an assumption that the establishment of good practice would obviate the air leakage problem. Neil B. Hutcheon, assistant director of the Division of Building Research at the National Research Council of Canada, initiated a Canadian drive to focus on air leakage as an essential element in moisture control in attics. Hutcheon (1950) may be the seminal document of his investigation, which continued throughout his career. He noted frost accumulation 10 times greater than would be predicted by "normal vapour transmission." He concluded forcefully:

> It seems necessary to assume some other mechanism for vapour migration than the usual one of vapour diffusion under vapour pressure difference, to explain the rate of moisture transmission. It is possible that leakage of warm, moist inside air outward and upward, carrying water vapour can account for this.

By 1954, his observations had been consolidated into research reports (Hutcheon 1954). Here, Hutcheon stated:

> The tendency for warm air to find its way upward is identical in principle to the situation in a chimney in which "draft" is produced. A column of air twenty feet high and one square foot will, at outside winter temperatures, weigh up to 0.35 pounds more than a similar column at indoor temperature. There is thus created a potential pressure of 0.35 pounds per square foot available to induce leakage of cold air at lower levels in a house and to force warm air out at the top. In other words, the warm air in a house tends to be "floated" up and out by the heavier cold air leaking in and collecting at lower levels.

His recommendations were for airtightness at the ceiling plane and for ventilation of the attic space.

Hinrichs

H.S. Hinrichs, in 1961 a research engineer with a manufacturer of various vent devices, conducted a study to determine the relative effectiveness of several devices (Hinrichs 1962). He used dissipation of smoke as an indicator of effectiveness and found that soffit and ridge ventilation provided greater dissipation than roof louvers, gable-end louvers, ridge only, soffit only or other combinations.

NBS "Summer and Whole House Ventilation"

"Summer and Whole House Ventilation" was published by the National Bureau of Standards (now NIST) in July 1979. The work was edited by Doug Burch. The general conclusion from the volume is that, while attic ventilation cools attic air significantly, cooling has little impact on the total heat gain and cooling load in a house.

Reagan and Acklam (1979) measured the solar reflectivity of many commonly used building materials and showed how those values can be effectively used in whole-house energy calculations. He concluded that "changing the roof color from dark to light does greatly reduce the summer roof heat gain of a typical southwestern house, but such a reduction has little effect on the summer total house heat gain because the roof heat gain is typically small to begin with compared to the total house heat gain." Wetherington (1979) noted that tile roofs operated at much lower temperatures than shingle roofs. Later research (Chandra and Moalla 1992) confirmed this observation, with both local airflow around the tile and evaporation of sorbed moisture as explanations.

Dutt and Harrje (1979) reported that houses with forced attic exhaust ventilation used more power during the air-conditioning season than did houses with natural attic ventilation. They also noted that air-conditioning use went up when the attic fan was put in operation. They attributed this to behavioral differences by the occupants, having noted that two large ceiling bypasses were sealed. However, the movement of conditioned air from the living space into the attic under the pressure difference created by the exhaust fan remains a strong likelihood. Grot and Siu (1979) reached the conclusion that the ceiling heat gain for a two-story townhouse is only a small portion (less than 10%) of the sensible cooling load of the air conditioner for a climate similar to that of central New Jersey. Though the attic fan can reduce the ceiling heat by as much as 25%, no difference in the operation of the air conditioner could be observed either under average or maximum conditions.

Burch and Treado (1979) reached the conclusion that attic ventilation is not an effective energy conservation procedure for houses with insulation thicknesses of 4 in. and 6.5 in. This was true even with air-conditioning supply ductwork in the attic. Compared to soffit venting, power venting or turbine venting produced a maximum reduction of 17% in the average duct heat gain rate. They also found that whole-house ventilation was an effective energy conservation procedure.

Modeling Efforts

To apply findings from case studies and laboratory studies, the measured values must come to be used in the validation of models. Several researchers worked in this field during the 1980s, including Peavy (1979), Wilkes (1989), Burch and Luna (1980), Gorman (1987), Forest and Walker (1993), and TenWolde (1995). Peavey (1979) and Wilkes (1989) were among the first to do validated temperature models. Burch and Gorman attempted some of the first attic performance models that included moisture. Gorman's work has been further developed by himself, Forest, and TenWolde.

Later Research

Cleary (1984a, 1984b, 1985; Cleary and Sonderegger 1987) was among the first researchers to establish the importance of moisture storage in attics. This concern was further developed by Harrje, Ford, and others. In an interesting article, Ford (1982) showed the close relationship between attic air temperature and dew-point temperature. (See Figure 6 [copied from that report].) Because dry-bulb temperature is a measure of energy and dew-point temperature is a measure of absolute humidity (mass), they are commonly taken to be independent quantities. It is temperature-driven sorption and desorption of moisture from the attic material that links them closely, as is shown.

Further recent works by a national laboratory (on reflective foils and laboratory testing in a large-scale climate simulator) and by Tom Forest have made significant contributions to our understanding of attic performance. Lstiburek and Carmody (1992) have made use of the most recent research findings.

CONCLUSIONS

The requirement for 1:300 attic ventilation appeared in January 1942 with no apparent basis in the research literature. With the publication in 1948 of the HHFA's "Condensation Control in Modern Buildings," the 1:300 ratio became a fixture of construction practice to the present day.

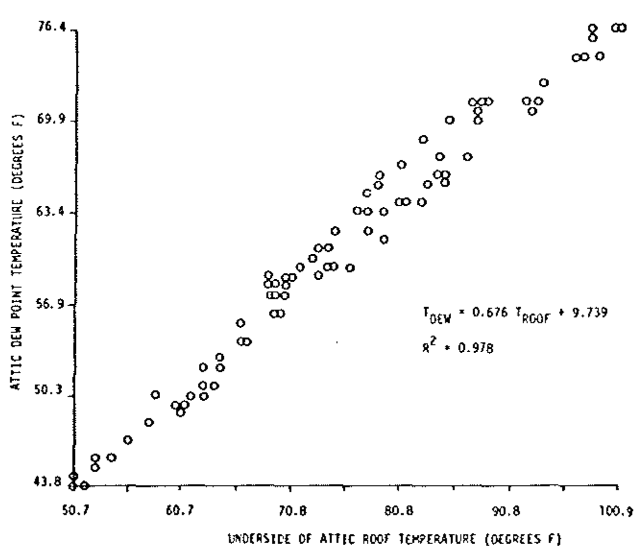

Figure 6 *Copied from Ford showing the interdependence of dry-bulb temperature and dew-point temperature in actual attic measurements.*

The research support for the need for the 1:300 attic ventilation rule is not strong. Rowley's 1939 research was conducted with no vapor barrier; his conclusion that ventilation is desirable even with a vapor barrier is unfounded. The Britton (1948) research showed that the tested unvented roof-ceiling assemblies performed satisfactorily, while the only vented assemblies that performed well were those with good vapor barriers. Jordan et al. found that screening can reduce the net free area of a vent by half, indoor humidity is a stronger determinant of moisture problems than either ventilation or vapor barriers, and with increasing insulation levels (up to 4 in. of mineral wool) "the amount of ventilation necessary to prevent or remove frost had to be greatly increased."

These results point in contradictory directions. Rowley demonstrated the effectiveness of 1:576 ventilation against diffusion. Britton demonstrated mixed effectiveness for ventilation and no ventilation. Jordan et al. demonstrated the insufficiency of 1:300 ventilation for diffusion moisture removal in well-insulated attics.

Although Britton's research noted the influence of air leakage on research results, he drew no conclusion about airtightness in practice. The prevention of air leakage became a desirable element of cold-weather construction due to the research of Hutcheon, beginning in 1950.

Studies in the late 1970s showed that attic ventilation was not effective at reducing cooling energy costs. Studies in the 1980s showed that moisture storage is an important element in the moisture balance in an attic.

Despite mixed research results, attic ventilation has become an element of almost all U.S. building codes and practice. Clearly, there is no significance to be attached to the particular ratio "1:300."

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