# OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

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PAPER 2

# VENTILATION, AIR INFILTRATION AND BUILDING OCCUPANT BEHAVIOR

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#### SYNOPSIS

The role of the occupant in buildings energy use has been evident in studies in many countries. Our experience since the early 1970's has indicated that energy use can vary by at least a factor of two solely on how the occupant operates the house or apartment. This often involves window use. For example, window and door openings, to cool an overheated dwelling, can take place at any time of the year. This paper describes work at Princeton which measured occupant ventilation behavior, and which provided feedback in an attempt to modify behavior.

Experiments have been conducted about the effect of informing the occupant as to when outdoor temperature is low enough that window opening would be the better choice than employing mechanical cooling methods. A small blue light visible to the occupants was used to supply this guidance, in conjunction with feedback to the occupants about cost.

In a large multifamily building, regular visual inspection of window openings, sometimes supplemented with infrared scanning, were used to identify the prevalence of these actions. Fan pressurization tests in the apartments indicated very tight construction with the windows closed. When comfort and perceived ventilation needs conflict with energy conservation, poor temperature regulation can be the culprit.

In another study, data were collected through open-ended interviews and a survey in the same multifamily building. Interviews asked about beliefs concerning need for fresh air, stuffiness, and perceived thermal comfort. In this building, which most residents considered too warm in the wintertime, window or door opening was typically used to reduce indoor temperature. Blower door tests were used to estimate infiltration in a single apartment at differing window apertures while energy balance calculations based on measured energy consumption and temperatures were used to estimate infiltration for the entire building. Tenants' reports of their perceptions are used to interpret the observed and reported ventilation behavior. Tenant perceptions are also related to measurement-based estimates of air infiltration rates.

#### 1. INTRODUCTION

From the beginning of our studies of energy conservation in buildings in the early 1970's at the Center for Energy and Environmental Studies, it was very evident that the occupant played a major role in energy use in the home by the way in which the home was operated. Our initial research into energy use was based on the analysis of monthly utility billing data, where clearly there was at least two-to-one variation in energy use for the total sample of 209 townhouses as well as for the 28 with identical orientation and design.<sup>1</sup> In a later series of measurements, even after 25% energy savings retrofits, there was still a wide spread in the energy appetite over the group of 30 houses that were being constantly monitored (hourly data from twelve channels of energy-related sensors) as shown in Figure 1. It was at that point in our monitoring effort that the highest energy user moved, (number 1 in the figure), and the new occupant promptly caused the home energy use to drop to the low end of our 30-house sample.





As our research extended from the Twin Rivers townhouses to older homes, and now to multi-family buildings, the role of the occupant continues to be an important part of the energy use research. To further substantiate that major energy consequences result from occupant effects, Figure 2 illustrates the repeated two-to-one type influence of occupants in a number of housing developments throughout the State of New Jersey.<sup>2</sup> In each neighborhood the same house construction was compared, building tightness was checked with blower doors, and heating system efficiency was checked using the latest instrumented auditing techniques.<sup>3</sup> Even with these items "controlled", occupant effects proved important. Occupant influence on energy use are not only an American phenomenon as shown by the review of occupant effects in the IEA Annex III handbook Guiding Principles Concerning Design of Experiments, Instrumentation, and Measuring Techniques.<sup>4</sup>



Figure 2. Histograms of estimated annual gas consumption for the six New Jersey Modules before the retrofits. Estimates predict the gas consumption during a year of "typical" weather (that is, a nine-year average temperature profile) based on the actual meter readings during 1978 and 1979.

# 2. OCCUPANT AWARENESS

One of the ways to attempt to reduce the energy waste associated with inappropriate occupant energy-related actions would be through an information campaign. Although we are often more prone to think of the heating season as a time when window habits can cause large increases in energy consumption in a dwelling, summer and the cooling season is another major opportunity for energy savings. However, the strategies differ sharply. Realizing there are periods, especially in the Southeastern United States, when windows should remain closed 24 hours a day, since the temperature never drops below 25°C and relative humidities of 70% or greater are the norm -- in many other areas there are extended periods when cooling would be more efficient if the windows were opened. When windows remain closed with complete reliance on air conditioning, heat generated within the building and residuals from solar radiation can cause the air conditioning system to run far into the night. Instrumented observations of ten heat pump homes<sup>5</sup> pointed out that air conditioning was still evident at outside temperatures of 7°C! Long before such nighttime temperatures were reached, it would have made sense to open windows.

In order to inform the occupant when window openings made sense and running the air conditioner did not, experiments were conducted by Seligman et al<sup>6</sup> using a "small blue light". The approach was as follows: an outside thermostat was placed in a location where it could measure temperature free from solar effects; the thermostat was connected to a blue light located in the kitchen near the telephone; the electrical connection was such that only when the air conditioner was operating would it be possible to activate the blue light, provided that the thermostat setting was exceeded.

The system interaction with the homeowner was that if the outside temperature was less than  $20^{\circ}$ C, and the air conditioner was still operating, the blue light would flash. In order to stop the light from flashing the occupant needed to turn off the air conditioner. The occupant was then anticipated to open the windows if additional cooling were required. When the outside temperature was above  $20^{\circ}$ C the light would not flash, no matter whether the air conditioning was on or off.

The study also involved feedback as a means of transmitting information to the homeowner as to whether they were consuming too much energy. Thermostat control was emphasized as the best way to reach energy conserving goals. Waste-indicating feedback from the research team about the total household energy use was a way to urge the homeowners to modify their thermostat settings to reduce energy consumption. Forty residents were chosen to be part of the study which included four conditions: blue light, feedback, blue light plus feedback, and control. The feedback was given three times each week by reading electric meters and then displaying the updated energy use graph on a 15 by 23 centimeter card attached to the kitchen window. Consumption per cooling degree hour was computed for each house prior to the study, and predicted consumption was based only on the consumption per degree hour index. Feedback information was based only upon the most recent days. The experiment was conducted in late summer, mid-August to mid-September, when air conditioning use is prevalent in New Jersey.

Prior to the experiment there were no significant differences between the groups. During the test period, only those days in which the outside temperature dropped below 20°C were included in the analysis, since this was the operational point for the blue light.

The results from these tests are summarized in Table 1 and point out 15.7% less electrical use for the blue light homeowners. The feedback alone had less effect on saving energy. Attitudes of the blue light homeowners ranged from enthusiastic to feeling that the flashing light was an intruder in their home. Certainly when one considers the heat pump study, mentioned previously, an indicator of what outside conditions are present and how they can reduce energy use is clearly needed.

	Blue Light Feedback	Feedback Alone	Blue Light Alone	Control
Sample size	10	10	10	10
During treatment*	18.30 (2.96)	20.61 (5.69)	18.24 (4.50)	22.76 (6.02)

Table 1						
Mean	Daily	Elect	ric Co	nsumption	(kWh)	
Feedba	ck and	Blue	Light	Signaling	Device	

Note: Standard deviations are given in parentheses. \*Adjusted for pretreatment differences by analysis of covariance.

### 3. <u>MULTIFAMILY STUDIES</u>

What is often lost when one moves to a multifamily building is the degree of occupant control over room temperatures. In even a preliminary study of multifamily buildings, one discovers that in the middle of the heating season many buildings have a significant number of windows at least partly open. If there was any doubt that heat was being lost, and energy wasted, one only need to use outside infrared thermography to document the losses.<sup>7</sup> The thermograms shown in Figure 3 pointed out how the warm room air exits and cold air enters individual windows in two apartment buildings; and depends upon relative location from the neutral plane for the relative flow rates.<sup>1</sup>

Although window replacement is often a popular energy retrofit from a window tightness standpoint, it could not be justified in the building being tested. The blower door tests in individual apartments indicated air exchange rates of less than 3 ACH for the existing casement windows.<sup>7</sup> With the windows closed, the ventilation level from air infiltration would be marginal.

To look at what are the actual infiltration rates taking place with the occupants controlling window openings requires sophisticated instrumentation. Bohac et al<sup>8</sup> have just completed a preliminary survey using constant concentration tracer gas (CCTG) equipment<sup>9-11</sup> to measure a test apartment and those apartments above and below and on either side. The study points out that although a seasonal-average air infiltration rate for an entire multifamily building may be estimated from a calculation of transmission losses and analysis of building data, such estimates usually suffer from regression parameters that are not well determined.<sup>12</sup> For the particular multifamily building under study an air infiltration rate of 1.6 ACH was estimated, with an uncertainty almost as large, as shown in Figure 4.

<sup>&</sup>lt;sup>1</sup>Opening upper windows tends to exhaust air, while opening lower windows tends to supply air to the building via the stack effect. Of course, unsteady effects and wind pressures can modify conditions for any given window. The higher the building, the greater the stack effect if good air flow communication exists between floors.





Figure 3. Thermograms of two multifamily buildings pointing out air infiltration related energy loss and variations in window flow pattern with building height.



Figure 4. Matching transmission loss energy use in a multifamily building to the heating system efficiency to provide ranges of possible air infiltration. The lower air infiltration bound was established with fan pressurization.

These measurements were based on normalized annual consumption, NAC, and a building energy loss coefficient, B. Direct measurement with the CCTG system shows air infiltration in the 0.1-0.2 range, with windows closed, but increasing rapidly to 2.5-3.8 ACH with a 5 cm. window openings. The variation over time was very dynamic as occupants in the surrounding apartments opened and closed windows as shown in Figure 5.

To evaluate the flow of air in the stairwells, Bohac et al<sup>8</sup> found constant injection of tracer gas to be a very useful technique. Again window openings were the key parameter, increasing the air infiltration rates by a factor of about 20.



Figure 5. Air infiltration variations due to occupant and weather effects in three apartments monitored with constant concentration tracer gas equipment.

## 4. INTERVIEWING THE TENANTS

To obtain a better idea of why the residents were opening windows in mid-winter and in general, their reasons for the heating and cooling management within the apartments, two sets of interviews were conducted. First was a set of twelve open-ended ethnographic interviews, designed to orient us to the ways which tenants thought about ventilation, window opening, and heating their apartments during the winter. Based on that information, a survey questionnaire was written up which was then used to interview all the residents (53 of the 57 occupied apartments). The results of those interviews are presented both as percentage answers from the survey, and as quotations when we feel that they are representative and assist in an understanding of the tenants' perceptions and motivations. Both are drawn from more complete reports of these investigations. 13, 14 As we describe below, the large amount of window opening behavior is due to overheating of the building, tenants desire for "fresh air" lack of other effective control mechanisms, and the tenants' interaction with the boiler operator.

Based on measured indoor air temperature of 26°C (79F) we suspected that more heat was being provided to the apartments than most residents wanted. This was confirmed in the survey, where 61% said they were sometimes too hot, while only 22% said they were sometimes too cold.

In these apartments, the control mechanism designed for tenant operation is the radiator valve. However, this was not the control mechanism favored by the tenants. First, some did not know about it or thought they were not supposed to use it -- in the 12 ethnographic interviews, two did not know there was a valve which controlled the heat, and four more did not think it was something which they could control Thus, half did not even consider the radiator valve as a control mechanism available to them. Also in the survey we asked about several strategies for controlling the environment. Percentages saying they used each strategy are:

Use of windows	848
Use of radiator valves	35%
Calling maintenance	29%
Use stove for heating	25%

When we asked the reasons for leaving the windows open, we used the questions based on reasons which had been given frequently during the ethnographic interviews:

Leave	wi	ndows	i c	pen for	r fresh a	air				90%
Have	to	open	a	window	because	too	tight	; or	stuffy	51%
Have	to	open	а	window	because	ther	e is	too	much heat	53%

Thus, while overheating is one important reason for opening windows, "fresh air" is an even more important one in frequency (although the aperture for fresh air is reported to be smaller than the aperture used to relieve overheating).

Most tenants described "fresh air" as being healthy, and as being important for a comfortable environment in their apartments. A few were specific about the opening needed for fresh air, one describing it as 4 to 6 inches (10-15 cm) and another as about half a foot (15 cm), others less specifically saying they left it "cracked". The amount of aperture for fresh air is not described as being something they varied through the heating season or in response to environmental conditions. Such aperture related ventilation rates have been measured and are shown in Figure 6.

Although we see that tenant-perceived need for "fresh air" was very important in this building, it may be a greater factor here than in other buildings. The first reason for this is the previously-mentioned low measured infiltration rates with all the windows closed. Since the measured rate is below the currently proposed American ventilation standard of 0.35 ACH applicable to this building, the residents' intuition that they need fresh air corresponds to the best engineering analysis available today. The second reason that "fresh air" may be more important in this building than average dwellings is that the residents are elderly. and many of the families of their childhood heated with wood or coal. Given the emissions levels of the traditional American wood and coal stoves, these people would have been correct in believing that some window opening was important for good health. We believe that there is not as much emphasis on fresh air by younger Americans, though we have not surveyed young people to verify this.

A final question is, why is the building overheated? To understand the high ventilation rates, it is crucial to understand overheating, since the combination of overheating and poor apartment-level controls are primary causes of the open windows and thus the high ventilation rate. Reports from other researchers studying US multifamily buildings also report large amounts of window opening, and thus it may be of general interest beyond the particular building we are studying.

Overheating seems to be due to the functioning of the boiler operator and the tenants, in which they interact and each work to optimize only relative to their local controls and feedback sources. The boiler operator responds to tenant complaints. He could respond by going up to the apartment to check for blocked pipes or nonfunctioning radiator valves, etc. However, since this would require a trip and interaction with an annoyed tenant, it seems that he more commonly adjusts a zone valve in the boiler room. The zone valve will raise the temperatures in from 10 to 20 apartments (depending on the zone), but it is a very easy adjustment to make. This zone adjustment is an inefficient response to a single complaint, since many or most of the tenants affected would have already been comfortable (or already too hot). However, the boiler operator is not provided any financial disincentive, nor does he even have any record or report showing him the energy consequence of this action.



Figure 6. Ventilation rate measured at four window apertures, with pressure held constant.<sup>15</sup> (Inferred coefficient of discharge is 0.73, in comparison to theoretical flow of 0.61 for a sharp-edged orifice.)

For their part, the tenants whose apartments are too hot can either complain, shut the radiator valves, or open the windows. Many residents do not want to be labeled a "complainer" and the maintenance staff may discourage complaints, which mean extra work. Further, many of the low-income elderly do not want to complain for fear of being "put out". Some residents do use the radiator valves, but, as mentioned previously, many either cannot turn the radiator valves or do not consider them as an option. Even with the valves off, the rooms are surrounded by overheated apartments, and may still be too hot. This leaves the windows as an option which is attractive in the residents terms. Windows are easy to use, cool the apartment quickly, don't require complaints, and additionally provide "fresh air".

In short, the boiler operator operates the system on the basis of avoiding complaints and minimizing effort, in the absence of financial feedback. The tenants operate on the basis of local adjustment (the windows to reduce temperature) and complaints only when absolutely necessary (when it is too cold, not when it is too hot).

Two further areas of research are planned or ongoing: quantification of number and amount of window openings, and study of the interactions between the boiler operator and the housing authority which runs the building. Window openings have been measured throughout the heating season in a visual window survey. This is performed by marking a pair of mimeographed sheets as shown in Figure 7, which show each side of the building, with all windows The researcher visually scans each row of windows, marking drawn. on the sheet the ones which are open and the approximate apertures of each. These data will be analyzed to determined seasonal patterns and their relationship to boiler operation and possible estimates of air infiltration/ventilation levels and to assess any changes which occur as a result of retrofits to the system or changes in operation.

The second area for continued research concerns the relationship between the boiler operator and the housing authority. Some of the management decisions of the operator can have serious financial effects on the management, but there seems to be no feedback mechanism, much less incentive to maintain efficient operation. We plan further interviews with the boiler operator and interviews with management, to determine the reasons for this and potential solutions.



WINDOW SURVEY Lumley Homes Asbury Park, N.J.



Figure 7. Example window survey sheets. Researcher has marked each open window with aperture in inches, or with "W" for wide open.

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