HEATING A MULTIFAMILY BUILDING: TENANT PERCEPTIONS AND BEHAVIOR

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ABSTRACT

This paper discusses tenant perceptions and behavior regarding heating and ventilation in a multifamily building. Data were collected at Lumley Homes, a 60-unit subsidized housing complex for senior citizens in New Jersey. The building has a central gas boiler which supplies steam to radiators throughout the building; gas is neither metered nor billed to individual apartments. The heating system is centrally controlled by a boiler operator. In the apartments, tenants can control the valves on each radiator. Residents often report that they have too much heat in the winter and many windows are open even on the coldest days. In trying to explain behavior in more detail than the simple statement "tenants don't pay for the heat," we model the actions of the tenants and the boiler operator as a self-regulating system that determines heating system operation through local optimization in the absence of economic incentives for energy conservation.

Two types of data are used: ethnographic interviews and a questionnaire survey of all the residents. We give quantitative measures of reported comfort and strategies for controlling comfort. We also qualitatively discuss the factors which tenants consider to be important for thermal comfort in the apartments and their reasons for using various control strategies. For example, if a resident is too hot in the winter, he or she may open the window, close the radiator valve, or complain to management. Survey data are used to quantify the choices tenants say they make and the ethnographic data are used to examine the factors involved in making their choices among the various options for comfort control.

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INTRODUCTION

Centrally-heated multifamily housing is considered a classic problem in the economics of energy conservation--the residents are not directly billed for their own energy use and have no direct financial motivation to use energy efficiently. We have undertaken a detailed study of one multifamily building to determine more precisely how economic and other factors conspire to reduce energy efficiency in such buildings. We find in this case that the problem of economic incentives being split between tenants and management does not explain many of the sources of inefficiency. Taking a model complementary to the economic one, we conceptualize the interactions among the tenants, maintenance staff, and management as a locally-optimizing system which controls heating and ventilation in the building. The system is locally-optimizing in that, while the parties optimize their local controls with respect to their own motivations and constraints, the overall control of the building may not be optimum for any of them.

Background

Our study is part of the growing body of research showing that occupant behavior has a major effect on energy consumption in multifamily buildings. Studies such as Diamond (1984) and Lipschutz, Diamond, and Sonderegger (1984) have concluded that behavioral rather than physical factors probably cause most of the variation in energy use among similar units in the same housing project. Studies of conversions from master billing to individual billing reported by McClelland (1980), Hackett (1984), and Linteris, Dutt, and Englander (1986) suggest that changes in behavior induced by conversion result in a reduction of energy waste. A review of further studies is given by Stern and Aronson (1984).

There is a lack of information about factors other than the incentive to minimize energy costs which influence behavior affecting energy use in buildings. Identifying such factors is important because conversion to individual metering is not always feasible for institutional reasons and we are not certain that such conversions are necessarily the best way of improving the efficiency of energy utilization in multifamily housing.

Objectives

To address this lack of information, we are studying Lumley Homes, a 60-unit apartment complex for senior citizens operated by the Asbury Park Housing Authority. In previous research there, we were struck by some

observations which suggested that to reach a complete understanding of the building's energy consumption patterns we should not limit our investigation to the physical systems (structural components, heating equipment, gas and electricity services) of the building. Wintertime indoor temperatures are very high--an average of 26 C (79 F) was measured by DeCicco *et al.* (1986)--while at the same time many apartment windows are left open. The boiler operator expresses a reluctance to turn down the central heating system, reporting that he fears it would result in tenant complaints. Informal questioning of tenants in early spring 1985 suggested that the majority were too hot.

In short, it seemed that the building was consuming more fuel than necessary, while most of the tenants were getting more heat than they needed. This could not be explained as a simple conflict of economic interest between management and tenants. In Lumley Homes, there are three interacting parties who affect the operation of the heating system: tenants, maintenance staff, and management. There appears to be a lack of economic incentives for conservation at each of these levels. Tenants do not pay for gas or electricity and the maintenance staff responsible for the heating system expresses no awareness of the utility bills paid by management, who have shown little practical concern for reducing energy bills in day-to-day operations. In the absence of economic incentives, the human control mechanisms governing the heating system must be optimized on the basis of other factors.

Thus, we approached the behavioral study with the following questions. To what extent is the high energy consumption simply due to the lack of financial incentives? What are the factors that influence decisions regarding the heating system on the part of the tenants, maintenance, and management? Are the complaints of a few residents driving the maintenance staff to overheat much of the building? How much responsibility and control over heat distribution do the tenants feel they have and how much does the maintenance staff feel they have? What are the tenants' comfort preferences and how do they manage the thermal environment of their apartments? Our interviews to date have concentrated primarily on the tenants and this paper will discuss their perceptions and behavior in more detail than those of the maintenance staff. We have not yet looked into factors influencing housing authority management with respect to energy use.

METHODS

We decided to survey the tenants in order to learn more about tenant comfort, in particular whether they felt too warm, and to determine how the tenants managed heat and ventilation in their apartments. Prior to a questionnaire-based survey of all tenants, we decided to conduct ethnographic interviews, which have proven successful in previous exploratory studies of energy behavior and energy cognition (Kempton and Montgomery 1982; Wilk and Wilhite 1982; Diamond 1984).

Ethnographic interviews

We interviewed twelve residents in late summer 1985. Following ethnographic methodology, we did not simply ask questions, but rather let the informants partially guide the discussion and elaborate on the points which they brought up. Here we include excerpts from the interviews, identified by a fictitious three-digit apartment number. The full notes from our ethnographic interviews are found in Kempton and DeCicco (1985).

The value of using ethnographic methods prior to the survey questionnaire was demonstrated by some responses which at first seemed to be contradictory or surprising. For example, interviews with several residents followed a sequence like the following. When we initially asked "How is the heat in your apartment?" the tenant replied "Fine, it works great." Then later, after more specific questions, the tenant said that she had to turn all the radiators off and open the windows to keep from overheating. We initially saw this as a contradiction, since a poorly regulated system which overheats even with all the radiators valves closed does not "work great." We later came to see that the apparent contradiction was due to the ways in which the respondent's perceptions differed from our own. Thus, the open-ended ethnographic interviews gave us a sense of how residents conceptualized and managed the heating system. We were then able to construct a more reliable survey instrument.

Survey questionnaire

Based on our findings from the ethnographic interviews, we decided to inquire about specific management practices rather than posing general questions about comfort. We began by focusing on specific objects related to the heating system, namely, radiators and windows. We thereby elicited the tenants' behavior regarding the heating system before asking them to evaluate it verbally. We also felt that the tenants would be less threatened by our intrusion and more responsive to our inquiries if we started each encounter by inspecting items in the apartment rather than by scrutinizing their personal feelings and actions. The questionnaire used for the survey is given in Kempton and DeCicco (1985).

In October 1985, we interviewed tenants in 53 of the 57 occupied apartments in the building. The population was comprised of 35 women, 15 men, and 3 couples. Two respondents who were judged to have given unusable responses were excluded from subsequent analysis, leaving a useful sample size of 51. Reported ages ranged from 55 to 92 with a median age of 73.

COMFORT PERCEPTIONS AND NEEDS

Here we describe the residents' perceptions of thermal comfort and need for ventilation. Our suspicion that the building might be warmer than

many residents would like was confirmed by responses to two survey questions about thermal comfort:

	YES	NO	N/A
Are you ever too cold?	11 (22%)	38 (75%)	2 (4%)
Are you ever too hot?	31 (61%)	17 (33%)	3 (6%)

We explain the preponderance of high temperatures by two factors: the tenants' perception that the heat works well if there is plenty of it and their expressed need for fresh air.

Plenty of heat means the heat works well

The ethnographic interviews showed that tenants viewed what we would call overheating as evidence that the building was excellently heated and that the heating system worked well. That is, tenants make the mental equation "plenty of heat means the heat works well." The initial response to the question "How was the heat in your apartment last winter?" given by eight of the twelve tenants in the ethnographic interviews was a positive response such as "very good" or "excellent."

Further questioning of those who gave an initially positive response indicated that most were aware that the heat and hot water were warmer than they needed to be. Nonetheless, most tended to view the system as functioning very well rather than being out of control or too hot. The heat was good because there was plenty of it and, we infer, because tenants could make themselves comfortable by adapting to the conditions using mechanisms which were readily available and easily understood.

The need for fresh air

In the ethnographic interviews, most tenants regarded fresh air as important for a comfortable environment in their apartments and for being healthy. Only one seemed to link having windows partly open for fresh air with energy waste. During the survey we made specific inquiries about the tenants' reasons for opening windows:

	YES	NO	N/A
Do you leave windows open for fresh air?	46 (90%)	5 (10%)	0
Do you ever have to open a window because it is too tight or stuffy?	26 (51%)	22 (43%)	3 (6%)
Do you ever have to open a window because there is too much heat?	27 (53%)	21 (41%)	3 (6%)

By comparing individual responses to the last two questions, we found that many tenants do indeed make a distinction between their apartment being "too tight" or "stuffy" (underventilated) and it being "too hot" (overheated) as reasons for opening windows.

During the ethnographic interviews, three tenants were specific about the window opening needed for fresh air as being about 4-6 inches (an amount which looks small visually compared to the amount that a casement

window can swing). Others reported less specifically that they always left windows "cracked" for fresh air. Since the fresh air opening does not seem to be adjusted during the heating season, the exact opening did not seem to be very salient to the resident.

Two factors may make fresh air more important in Lumley Homes than in other buildings. First, the parents of these elderly residents heated with wood or coal and would have been correct in believing (and teaching their children) that fresh air is important for good health[1]. Second, tracer gas measurements by Bohac, Dutt, and Feuermann in a Lumley Homes apartment with the windows closed showed a natural infiltration rate of about 0.2 air changes per hour (ACH). This value is lower than the currently proposed American ventilation standard of 0.35 ACH applicable to the building[2], indicating that there may be a sound physical reason for these tenants to leave their windows open for "fresh air."

COMFORT CONTROL OPTIONS

From an engineering viewpoint, we are studying a building whose heating system is poorly controlled. We find little use of radiator valves, which are the comfort control mechanisms engineered into the system for use by the occupants. The radiator valves are often difficult to turn or not working properly and some residents do not even know that they can be used to control the heat. In effect, the occupants are not offered means of control which would enable them to regulate the heating system directly and easily. Nevertheless, from the viewpoint of the residents themselves, the building is not poorly controlled. They use mechanisms not designed as part of the heating system: windows to reduce temperature, the stove and complaining to maintenance personnel to increase it.

We will not dwell here on the heat sources beyond the tenants' control: uninsulated steam risers, hot water pipes in the walls and floor, and heat gains from adjacent apartments. Even with radiators turned completely off, these sources provide considerable heat. As for the means of comfort control available to the tenants, we focus in turn on the windows, radiators, stove, and the choice of complaining to management versus adapting to the given conditions. We asked about each of these in the survey:

Behavior related to comfort control	Fraction of tenants
Any use of individual windows	84 %
Any use of radiator valves	35 %
Calling maintenance	29 %
Use of stove for heating	25 %

These four comfort control options are discussed in the subsections below.

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[1]Ken Gadsby points out that this advice was once even included in secondary school health texts.

[2]David Harrje, personal communication.

Window use

Windows are the most important mechanism by which the residents of Lumley Homes regulate heating and ventilation in their apartments. Tenants reported the importance of window use during the ethnographic interviews and it was the control action reported most often during the survey: 84% said they used windows during the winter. The second and third most commonly reported actions also concerned windows: 82% use the storm windows and 75% use the window latches.

There are several reasons for the importance of windows to the tenants. First, there is the frequently expressed desire for fresh air. Second, window opening is needed to alleviate overheating. Third, opening and closing apartment windows have immediate effects on the thermal environment which are well understood by the tenants. Finally, in contrast to radiator valves, windows are considered easy to operate.

Among the reasons for opening windows, the need for fresh air was foremost in the minds of the tenants--we discussed this in detail previously. For fresh air, windows were left "cracked" or "cracked open" throughout the heating season. No one reported that the window opening for "fresh air" was adjusted to compensate for differing environmental conditions or to maintain a constant ventilation rate.

The second use for windows was to regulate indoor temperature. To reduce temperature, "cracked" windows might be opened further, or other windows might be opened. When used for temperature regulation, the window opening was likely to be adjusted for environmental conditions. Two respondents described elaborate strategies for window adjustment based on wind direction, outdoor temperature, and activity level. The resident of apartment 161 summed it up: "You can control the temperature very well with the windows."

Most of those who consciously opened windows to relieve the abundance of heat understood that heat went out windows but they considered this to be usual and necessary for comfort in a "well-heated" building like Lumley Homes. For example, the tenant in apartment 194 said

> When it gets too hot in here, we got the windows standing wide open with all the heat going out. I don't like a lot of heat, because too much heat makes me feel like I'm going to faint. We have our windows open--we don't like to do it--because it is the only way to get some air. (Here she seemed use "get some air" to mean "keep it from being uncomfortably warm.") And it's not good because you get a draft.

This person was unusual in mentioning drafts--she was the only one in the ethnographic interviews to describe drafts as a problem. Only two persons

mentioned that having heat go out windows was wasteful. One of these was the tenant in apartment 194, who later in her interview said

> It's nice to get that heat, but it's not good to get too much heat. It's a shame to waste it. It's just like food; some people get plenty and others don't have enough to eat.

In general, little disincentive to opening windows was visible in the ethnographic interviews.

Given the distinction between the need for fresh air and heat reduction, and the lack of conscious management of window opening for fresh air, we were able in retrospect to understand a seeming anomoly. Early in the interviews, we asked "Do you ever have to leave the windows open because it's too hot?" Several respondents initially answered "no" but later in the interview told us that they had the windows open all winter for fresh air. They did not see this as a contradiction since it is a different use of the window and because it is not active management.

Radiator use

In contrast to widespread use of windows, the use of radiator valves is less common among the residents of Lumley Homes. Only 18 (35%) of those surveyed ever opened or closed their radiator valves. Of the twelve tenants in the ethnographic interviews, two were not aware that the radiators could be controlled within their apartments and four others did not consider the radiators something which they could control.

Because of the constant, abundant supply of steam to the building during the heating season (interrupted only during night setback), tenants rarely need more heat. The resident of apartment 163 told us

> The heat is beautiful. I don't have the radiators on at all, because the pipes are plenty hot. I don't like too much heat anyway. I've always been just right as long as I've lived here.

Of the six who said they get more heat than they need, four turned off their radiators, one wasn't able to turn the valve and was reluctant to call maintenance, and one, who had moved in recently, simply "adjusted" to the high temperatures. We found stuck valves in 18 of the 53 apartments surveyed. Radiator valves that malfunctioned by still letting heat through even when closed were reported by 7 of the 27 tenants who responded to that question. The tenants of one apartment where we interviewed had had their valves replaced upon their request. A tenant who was too cold after maintenance closed a valve used the stove rather than turning the valve back on. Also, when her visitor was hot, they opened the windows rather than closing the radiator or doing both.

In short, it seems that radiator adjustment is not a comfort control option favored by the tenants in Lumley Homes. They generally find it less useful than opening windows when they want to reduce the temperature.

Use of stove for heating

A suspicion that some residents used their kitchen stoves for supplemental space heating was first aroused when we inspected gas billing data for the building. There is a separate central meter for cooking gas. The monthly consumption records show regular peaks in spring and fall, with a particularly large October peak just prior to when the central heat is turned on. Stove or oven use for apartment heating was confirmed by the tenants themselves. In the twelve ethnographic interviews, three tenants explicitly discussed their use of the stove for space heating; we strongly suspected use of it (or a space heater) in a fourth apartment. In the survey, 13 (25%) told use that they use the oven or stove for heat. Seven of the ten who described stove use schedules said they use it in the fall or when the central heat is off. All who reported how long they used it for heat said that they left it on for periods of two hours or less. Similarly, in the ethnographic interviews, the two tenants who reported specific stove use practices said that they would turn the stove on and off according to need rather than leave it running continuously.

Complaints and adaptation

After the mechanical means for controlling conditions in their apartments, there remain two further options for tenants: complaining to management to get them to change the conditions or adapting to the conditions, thereby coming to view them as tolerable, perhaps even expected and preferred. The survey showed that 15 (29%) of the tenants reported calling maintenance because they had a problem with the heat. Adaptation can not be quantified like this and is difficult to evaluate in a brief survey, but we inferred adaptive behavior from our conversations with tenants and from the ethnographic interviews.

During the ethnographic interviews we observed that the tenants seemed to fall into two distinct categories: those who would complain and those who would not. With two exceptions, the tenants interviewed "make do" (adapt) rather than complain or seek changes; the statement "I'm not one to complain" is typical. This adaptation only works well given certain characteristics of their situation. One necessary characteristic is that the heating system functions in a way to which they can adapt easily--we would not expect to see adaptation quite so readily in the face of underheating as we do in the case of overheating. Another characteristic may be the perception held by some tenants that complaining may be futile because the management and staff are unwilling or unable to remedy the situation.

The ethnographic interviews provided some further insights on inhibitions to complaining as a control strategy. Two tenants sought to change problems rather than simply adapt to them. One, who tried to organize other tenants, complained that they would say "I don't want to get involved" or "They'll put me out." While we restricted our questions to the heating system, these two tenants both expressed strong dissatisfaction with the management and maintenance of the building as a whole as well as

with the heating system. In both of these cases, the two characteristics we hypothesize as underlying the adaption tendency are missing. Both of the dissatisfied tenants were sometimes underheated and both believed that by complaining they could eventually get corrective action.

Many tenants really had no complaints. The perception that plenty of heat means the heat works well, along with their ability to regulate high apartment temperatures by opening windows, enables them to adapt easily to what we might view as overheated conditions. While many tenants expressed that they were sometimes too hot, few of them saw this as a big problem, at least not one with which they couldn't readily cope themselves. If an apartment is too hot, the tenant adjusts to it by opening windows, possibly turning radiators off, and moreover, growing to like it that way. We infer that the tenants optimize the way they deal with given conditions, and once adapted prefer the known *status quo* to changes.

ECONOMIC FACTORS AND IMPROVING EFFICIENCY

In this section, we will discuss the economic factors affecting the tenants' perceptions and behavior regarding the heating system. We make a contrast with the factors influencing people who pay their own utility bills. We also discuss the role of the boiler operator and management of Lumley Homes as far as operation of the heating system is concerned. A model of the situation as a locally-optimizing system is presented, which furthers our understanding of the interaction between the various parties who determine heating system operation. Finally, we present some suggestions for making the system more energy efficient.

Tenants versus homeowners

In their economic motivations underlying comfort management, the tenants of Lumley Homes contrast sharply with the homeowners of single-family residences in Michigan studied previously by one of the authors (Kempton and Montgomery 1982). While the Lumley tenants made little mention of cost and efficiency factors, the homeowners were acutely aware of the relationship between thermostat setting, window opening, and fuel cost.

The homeowners all received monthly bills which they had to pay and which informed them of the quantity of fuel they had consumed. Although a few of the homeowners had high (above 20 C) thermostat settings, they were making a deliberate choice to pay for what they considered to be a more comfortable environment. Reported window opening in this group was limited to a few who closed their bedroom door and opened the window overnight. In Lumley Homes, the tenants are not billed for utilities. During the ethnographic interviews, only two tenants made any mention of the inefficiency of using windows to reduce indoor temperature. No tenants mentioned a link between hot water temperature and energy consumption. In fact, the cost of heating the building, borne by the housing authority, was never mentioned by the tenants interviewed.

Economic motives are probably not the only cause of the differences between these two groups. The heads of household in the single-family homes were on average, younger, more affluent, and better educated. They could control heating through a thermostat, which is much easier to adjust than radiator valves, both in physical strength required and in clarity of control function. More generally, elderly people may feel less able to control their physical surroundings. Another study of housing for the elderly found energy control problems to be only a part of a general need to help residents "better understand and control their environment" (Diamond 1984: 342).

Maintenance staff

In Lumley Homes, the lack of financial incentives extends beyond the tenants to the maintenance staff and even to the management of the housing authority. In particular, the boiler operator, who actually controls the level of heat output from the central heating system, does not appear to have economic incentives for saving energy. The boiler operator is also head of maintenance and so has responsibility for all building operations and maintenance as well as groundskeeping at the seven public housing projects run by the Asbury Park Housing Authority. Running the heating systems is thus but one part of his overall duties. He has not reported having instructions or any other incentive from higher management to minimize fuel consumption.

The boiler operator has expressed a sensitivity to tenants' complaints about lack of heat or hot water. His procedure regarding the heating system is to control it so as to provide plenty of heat to the building. Based on his experience, he sometimes adjusts the boiler controls according to weather conditions. If there is a complaint, he may go to the boiler room and increase the valve opening for the part of the building where the complaint occurred; this increases the steam delivery to 10 or more apartments in response to one complaint. On the other hand, he may ignore the complaint if he feels that the tenant is getting enough heat and is "just a complainer." Neither the housing authority nor the boilerman keep a record of heating complaints and the boilerman rarely (if ever) goes to apartments to investigate heating complaints.

During the 1985-86 heating season, we attempted to establish the use of a form to record heat complaints and to have a maintenance staff person go to an apartment in order to investigate a complaint. We hoped to thereby obtain information on the source, frequency, and response to heating problems. However, the heat complaint forms were not used. One reason may be that many complaints do not come through the maintenance office, but rather through person-to-person contact between the boilerman and a few tenants. For these reasons, our attempt to formalize the process was not successful. We are planning further investigations to determine how the boilerman is influenced and how to address the problem of the system being run at levels that overheat the building.

A locally-optimizing model of heating system control

The tenants, the boiler operator, and the space heating equipment at Lumley Homes may be thought of as a self-regulating dynamic system in which each party performs local optimizations based on the control mechanisms, constraints, and economic incentives which they perceive. In this context, we can describe two control subsystems which regulate the central heating operation and interior temperatures in the building. First, the tenants control temperature and ventilation within their apartments by opening or closing windows, adjusting radiators, complaining to maintenance, and using the stove (listed by decreasing incidence). Second, the steam output and distribution from the central boiler are controlled by the boiler operator, who is stimulated by the calendar date (for beginning and end of the heating season), weather conditions, and complaints from the tenants. At Lumley Homes, there are no fuel cost economic incentives, but there are economic analogues for the incentives that do affect the tenants and boiler operator, as described below.

In the tenant/apartment subsystem, complaints are more expensive than the other options for comfort control. A resident does not want to be labeled a "complainer." The staff may discourage complaints, which usually mean extra work for them. Window use, on the other hand, is a very inexpensive option for the tenants. Thus, tenants will complain about not having enough heat, for which they can compensate only with radiators (which don't always work or are difficult to use) or the stove (which has limited effectiveness and is undesirable for safety reasons). They will not complain about too much heat, for which they can easily compensate by opening a window.

In the boiler operator/heating equipment subsystem, going up to an apartment to check out a heat complaint is more expensive than making a valve adjustment in the boiler room. The valve adjustment takes just a few seconds and can be done as part of normal daily rounds. Checking for problems with the radiators or steam pipes in an apartment, however, requires a special trip up to the apartment, interaction with the tenant (and worse, a complaining tenant!), and an effort to diagnose the problem. Adjusting the valve in the boiler room is the option chosen by the boiler operator when he decides to act on a heating complaint; it is cheap in time and effort while its energy expense is not salient to him.

Suggestions for improvement

We believe that there is quite a bit of leeway to reduce the amount of heat supplied to the building while satisfying the tenants, even though 33% replied "No" to the question of whether they were ever too hot. However, such a reduction may require a period of adjustment on the part of the tenants in order that their perception be altered from "plenty of heat means the heat works well" to "just enough heat means the heat works well." It could initially result in increased complaints. Without a better method of addressing complaints, such a change may not last--the boiler operator will find it easier to just crank the heat up high again.

The central control settings were in fact lowered by Princeton researchers earlier in the project; there was some drop in interior temperature and a reduction in gas consumption, but the measured energy savings could not be conclusively attributed to the control changes (DeCicco *et al.* 1986). The boiler operator reverted back to his customary settings when we ceased our intervention in his operations.

Although our attempt to get the maintenance staff to check out heating problems in the apartments was unsuccessful, it may be worth trying again if better incentives are provided. For example, we could give the boiler operator or other maintenance person a financial incentive or make it more specifically a part of his duties. (Housing authority management had approved our plan previously, but otherwise they did not get involved in implementing it.)

Some energy savings could probably be achieved by simply increasing the control which residents have over the heating system components in their own apartments. For example, non-working radiator valves could be replaced. Knobs could be tightened to insure that they move the valve stem, and the small knobs (5 cm diameter) could be replaced by T-bars, which would be easier for an elderly person to turn (there is clearance for a 10 cm turning diameter). In apartments where the residents report being too hot, it would certainly be desirable to close the valves and insure that they do not pass steam. Such apartments can be reliably identified only by a survey; most such probems will not have been independently reported by the tenants to the maintenance office. Insulation of the risers (pipes carrying steam to upper floors) would help in apartments which the residents now consider overheated.

The above suggestions may be collectively described as more active management of the existing heat distribution system. They involve both physical retrofits and behavioral changes on the part of tenants and maintenance personnel. We note that there are different heating requirements in different apartments due to their locations in the building and varying comfort preferences among the residents. For instance, based on the ethnographic interviews, it appears that several of the apartments which are sometimes too cold are located on the upper floors of one wing of the building. Nothing we have learned so far implies that more active management of the distribution system would be insufficient to more efficiently meet the differing needs for heat, but we will not know this for sure until we've tried it. If a few tenants do not get enough heat even after improving distributional control, it might be desirable to give these tenants individual space heaters in order to avoid running the central system at very high levels just to satisfy them. Further study is needed, both on the feasibility of these retrofits and on the economics of alternatives such as retrofit with a decentralized system.

CONCLUSION

We have proposed a model of the behavioral aspects of space heating in a multifamily building; in this model we conceptualize the interactions

between the tenants and maintenance staff (particularly the boiler operator) as a locally-optimizing system. The parties in this system make decisions and take actions that determine the operation of the heating equipment and the thermal conditions in the apartments. Comfort-regulating behavior by the tenants is constrained by their understanding of the mechanisms available and is chosen according to the factors salient to them, which do not include any need to minimize energy costs. Absence of the need to minimize energy costs is also apparent in the behavior of the boiler operator when he runs the heating system and addresses whatever complaints he gets from the tenants. We thus express our diagnosis as a lack of feedback about costs, a limited ability to effectively control the heating equipment, and a set of supporting factors such as the desire for fresh air, the perception that plenty of heat means the heat works well, and a reluctance to be labeled a complainer. We expect this model to be useful in making inferences about heating system operation in other multifamily buildings, particularly public housing, where the situation is similar to that found in Lumley Homes.

The implication of this analysis for improving energy efficiency in centrally-heated multifamily buildings is twofold. First, a better capability for heating system control by tenants and maintenance is needed. To this end we suggest retrofits such as insulating the risers, keeping radiator valves in good repair, adding easier-to-use knobs, and possibly providing individual space heaters to apartments suffering from a systemic lack of heat if other measures fail. Second, it would be helpful to have some sort of fuel cost feedback in order to provide economic incentives for energy conserving behavior by tenants and maintenance staff. Future research is needed to identify the reasons why energy cost factors are apparently absent from the decision making processes of the maintenance staff, who determine heating system operation, and the housing authority management, who pay the bills.

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