The Parable of the Frog:
Introducing New Temperature Regimes in Multifamily Housing

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ABSTRACT

Improvement of space temperature control is a common element in energy conservation programs in existing multifamily housing. Acceptance of new temperature regimes by on-site management and residents is critical to the perception of project success. New control systems with remote data access and remote programmability provide capabilities that are significant to the introduction of new temperature regimes and that were not available with previous technologies. Commissioning of such systems needs to consider not only the proper functioning of the components but also the adjustment of set-points and responses of residents. Examples are provided of data utilization for improved control strategy and of acceptance under varying implementation strategies.

Introduction: Energy Efficiency and Behavior

Since President Jimmy Carter's sweater speech in 1977, where energy conservation became equated with "freezing in the dark", advocates have tended to emphasize energy efficiency – provision of the same end-use services with less expenditure of energy. Such a technological solution says that we can have the same with less. Our measures are intended to perform their efficiency magic invisibly, without any behavior change from us.

Behavioral approaches have been resurgent – smart-growth planning to affect how people travel, market transformation to affect manufacturer production and consumer purchasing decisions. Conditioning of built environments is another area where major energy savings are to be found by changing end-use conditions in noticeable ways.

Practitioners who have worked with temperature controls understand well the behavioral dimension of their work. The thermal environment is the most common source of complaint in commercial properties. Changing thermal controls means changing one of the most sensitive sensory experiences of people who use a space. Acceptance or rejection of altered conditions spells success or failure for many an HVAC project.

This paper will suggest two points with specific reference to multifamily (apartment) buildings in New York City (NYC): (1) that gradual temperature change provides better resident acceptance of new conditions, with associated better project performance and persistence and (2) that new generations of controls with important information-technology (IT) elements can enable gradual introduction of new temperature regimes as has not previously been feasible.

Characterizing Residential Temperature Regimes

Residential temperatures in the US can be estimated to be in the range of 68-74 degrees F for daytime heating (with programmed setbacks for night and unoccupied periods), provided from a household furnace or boiler. A single thermostat is the most common control. Thermostats may be electro-mechanical or with electronic components and programmable but in either case are local, that is, operating with respect only to local conditions. Communicating thermostats, although now available, are still rare. Residential cooling's regime is generally similar although with a prevalence of individual room units with an integral and typically non-calibrated (i.e., –"warmer/cooler" knob) thermostat. Characterized in this way, the residential sector is marked by individual household control of their own temperatures that is generally associated with their own individual responsibility for energy costs.

The Multifamily Housing Segment

In older, dense urban areas such as NYC, however, this regime does not pertain for most of the large segment of multifamily housing. The temperature regime for this segment in NYC can be characterized as having:

- Central (shared) heating plant with little or no local control, resulting in over-heating, 78-84 degrees Fahrenheit (F) commonly observed, or imbalanced heating (5-10 degree F range between different parts of a building), and window-opening;
- Heating costs born by the property owner and service provided to residents without metering, as part of lease and legal requirements with significant penalties for under-supply;
- A small but significant sub-segment of electric heating, most commonly resistance baseboard, with non-calibrated thermostat integral to the heating element and service provided without metering from a building master-meter;
- Cooling provided most commonly by individual room units with limited control capabilities, most commonly on individual apartment meters but with a significant sub-segment on a building master-meter and temperatures of 68-70 degrees common. There is little or no programmability of unit AC, which leads to fairly common near-continuous operation, when no one is home and/or at night.

One trend has been to attempt to alter this situation of common services, through sub-metering and through installation of separate heating units for individual apartments, to approximate the dominant single-family home model [Lstiburek 2005]. This paper explores the possibilities for addressing the multifamily temperature regime, in particular over-heating, while maintaining the common plant and shared services platform.

Background on Thermal Comfort

Human thermal comfort is found to be achieved, across a wide range of cultures and conditions, in a range of air temperatures ranging from 65 – 85 degrees F. But comfort within this range depends significantly on related environmental conditions such as air movement, air moisture content, radiative effects, and behavioral factors such as clothing and activity levels. Age, health and gender are also found to be significant variables in thermal comfort requirements [ASHRAE 2004].

Humidity and moisture content of air are major factors in thermal comfort, especially for cooling. The science of psychometrics exists specifically to quantify the air-drying or moisture-adding requirements of outdoor air streams as they are conditioned. Radiant heating takes advantage of the lower temperatures required for perceived comfort when whole surfaces are warmed. Much of what we think of as aesthetic qualities – of gardens and hearths, for example – are related to these kinds of conditions [Heschong 1979].

Temperature “bands”, of roughly 5 degree F, are introduced in relation to perceived comfort. Research suggests that temperature sensitivity can be usefully calibrated in such segments. A change in user evaluation of comfort level seems to occur with changes in space temperature of this magnitude [ASHRAE 2004].

Related to temperature bands but not discussed in this literature is the perception of on-going temperature variations or “swings” that are normal to the operation of controls. Systems working cyclically utilize a “differential” setting above and below the target controlled variable (setpoint) to avoid excessive on-off chatter. A typical 2-degree differential will produce a 4-degree temperature swing, close to the 5-degree threshold of change in perceived space temperature satisfaction.

Buildings can have various difficult heating challenges based on their type of construction and operating conditions. Variables that must be considered include

- Thermal mass of the construction
- Thermal mass of the radiation
- On/Off Cycling periods
- Air movement and infiltration

Thus, in warm-air heated, light frame construction occupants may complain of thermal discomfort even with a reasonable thermostat setting. Neither the heating system nor the building has much thermal inertia, so the dead-band temperature swings are readily felt.

NYC Multifamily Construction

In NYC multifamily housing a common situation is high-mass masonry (no inner wall insulation) with high-mass free-standing cast-iron radiation. Steam is cycled with on-times in relation to outdoor temperature, that is, via an “open loop control” in which the controlled variable (apartment temperature) does not feedback as a control signal. With high thermal momentum, limited local control, and, possibly, small steam leaks adding moisture, residents feel their indoor environment to be oppressively “stuffy” and open windows. High air flow (draftiness) then lowers the perceived temperature so that we find the worst case scenario of maintaining temperatures in the 80’s with open windows! NYC local laws reinforce this pattern with inspectors responding to phone complaints and stiff fines if under-heating or incorrect system settings (below 68 degrees during daytime) are found.

The situation in larger centrally heated apartment buildings is further aggravated by heating imbalance, which is driven by another complex of factors:

- Unequal hydronic flows (for steam, time-differentiated arrival of steam to different terminal points in the system);
- Varying solar and wind exposures;
- Loads that vary due to internal stack-effect induced infiltration (generally at lower floors)

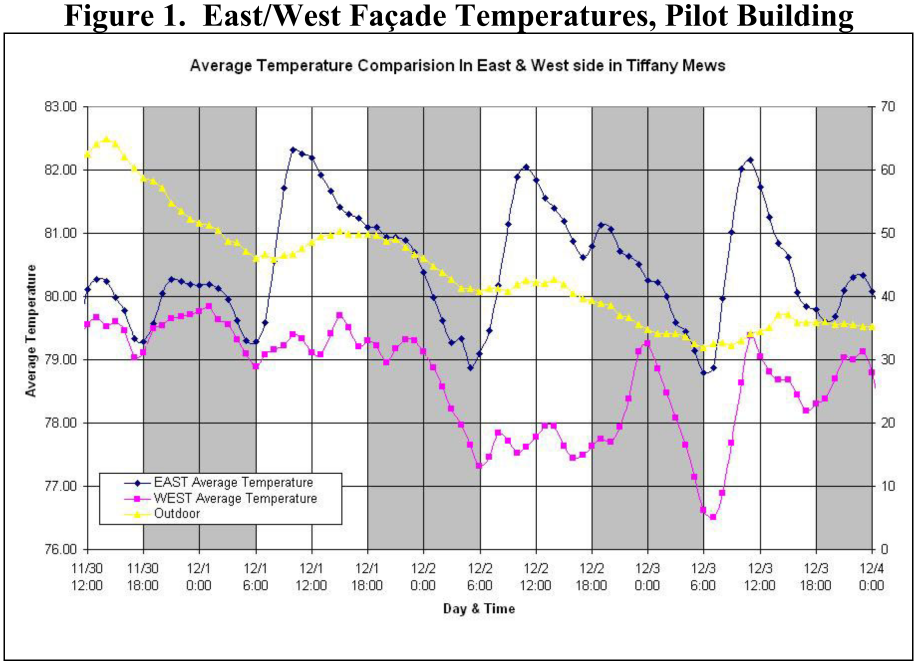
When imbalance occurs, the coldest occupant, in effect, becomes the thermostat, while residents in warmer areas open their windows.

Can We Drive Down Temperatures Without Driving Up Complaints?

Since the 1980's there have been various efforts to introduce apartment building boiler controllers based on apartment temperature (closed loop) feedback. While never displacing the dominant outdoor reset (open loop) system (the dominant manufacturer of which is the HeatTimer Corporation), enough experience was gained to demonstrate significant savings opportunity and eventually even HeatTimer added an option for feedback function from sampled apartment temperatures. In 2004 it introduced a new product line with web-based interface and sensor network integration, including wireless temperature sensors for apartments. The Assisted Multifamily Program (AMP) of the New York State Energy Research and Development Authority (NYSERDA) requires of all its projects with over twenty apartments installation of what is termed an Energy Management System that includes apartment temperature sensing with remotely accessible data.

With the market now firmly moving in this direction, many apartment building operators will have the opportunity to try driving apartment temperatures downward. The intelligence they are able to apply in this effort will greatly influence their success. It is relatively easy to save energy with a temperature feedback that eliminates uniform overheating across a building. With balanced distribution, pushing down an average temperature may approximate this. But doing so risks ignoring imbalances, such that some apartments slip below a comfort level while others remain above. Figure 1, drawn from a pilot project of the Association for Energy Affordability (AEA) where all apartments have temperature sensors, shows how closely monitored temperature dynamics can be necessary to optimally engineer a temperature reduction program.

Figure 1. East/West Façade Temperatures, Pilot Building



Source: Association for Energy Affordability (AEA)

East facade temperatures can be seen subject to significant morning heat gain. Control feedback that recognized but misunderstood this temperature affect would provide unsatisfactory control action for the rest of the building. On the other hand, adjusting heat supplied *just to this* *part of the building and just under this condition* would enable local temperature overshoot to be moderated. Being able to see the data makes a strategic approach to control changes possible.

Controllers that use temperature data blindly will under-optimize and/or cause comfort problems and complaints. Effort in this direction will create a need for steam balancing, the basic techniques of which are well understood (Holohan 1992) but application of which have been constrained by absence of feedback data. Making large amounts of data available as feedback will support system adjustment and drive savings. But it will also drive a need for visualization tools that can be utilized by operators who, in turn, must be equipped with new understandings and skills.

The Parable of the Frog

If you put a frog into very hot water he will struggle to get out. But if you put him into room temperature water and very gradually heat it, he will quite happily boil to death.

Equally important to understanding the building's thermal patterns is understanding and appreciating residents' perceptions of their heat and their sensitivity to change.

Over the years I have been told numerous times, standing in stiflingly hot apartments, that the temperature is fine but windows must be kept open in order to breathe properly. It is exceedingly rare to find an apartment with a thermometer on the wall. Yet everyone seems to know quite well if their heat is good or deficient. People blend their senses, such that the sensation of a hot radiator, sound of hissing steam, gurgling water and banging pipes tells them that they're getting proper heat. Comfort is heavily determined by what one is accustomed to. Rapid change is unsettling.

A hypothesis of our work has been that gradualism matters. We believe that residents will react more strongly to dramatic change than minor change that may even be below a perceptual or evaluative threshold. Project practitioners with temperature control experience well know that a complaint usually trumps energy savings. Moreover, the time spent responding to complaints can easily destroy the economics of a project. Ideally, new temperature regimes would be introduced very gradually, with small change increments so that people acclimate to new conditions rather than respond to drastic changes. The pilot work reported on below provides some preliminary testing of this hypothesis.

How Does New Technology Make New Strategies Feasible?

Gradual temperature adjustment has not been possible with conventional technologies of thermostats or thermostatic radiator valves. Each setpoint change requires access into an apartment, time-consuming at best and often not easy to arrange and schedule. So temperature set-points are established based on the assumption that it's probably a one-shot deal. If our initial space temperature is 80 degrees and we have only one adjustment opportunity, we will probably choose a setting of 73 or 74 degrees – a notable change, exceeding the five degree temperature band of thermal sensitivity. In relation to this project situation, consider the following capabilities of a new generation of communicating, web-based control and monitoring technology:

- Well-sampled temperature data provides baseline information to inform new settings, strategies, and expectations.

- Remote access to data enables repeated set-point changes at minimal expense from a central control location.
- Feedback data allows observation of control calibration, identification of malfunctions, tampering, and use of auxiliary heating sources.
- Temperature results are fully documented and easy to review.
- A communications infrastructure is put in place that has the potential for extension to other functions such as cooling.

Where terminal devices have digital, communicating control, such as in AEA's electric heating and room unit air-conditioning pilots, still more capabilities emerge:

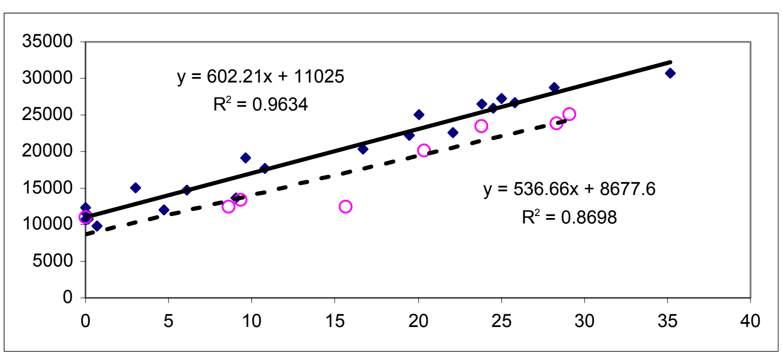
- Set-point and program changes can be made universally across all points or customized to individual cases or by pre-set rules.
- Digital control allows set-point changes in very small increments, fractions of degrees.
- Complaints can be addressed by remote reset. An uncomfortable resident can, without too much trouble, receive prompt customized attention.
- Individual apartment control points can be programmed for special needs, adding an element of resident "friendliness" that can help acceptance.
- Advantages from building-wide networking such as apartment automation, peak demand limiting and demand responsiveness

A Tale of Two Managements

Having the technology, however, does not necessarily mean that it will be used well. Since 2003 AEA has piloted installations in two similar but separately owned and managed low-income high-rise complexes. Both have electric baseboard heating. Based on limited sample measurements both appeared overheated, the first site probably more so. Neither site had any night setback. Results over the first two years are suggestive of strategic dimensions in the introduction and management of temperature change.[1]

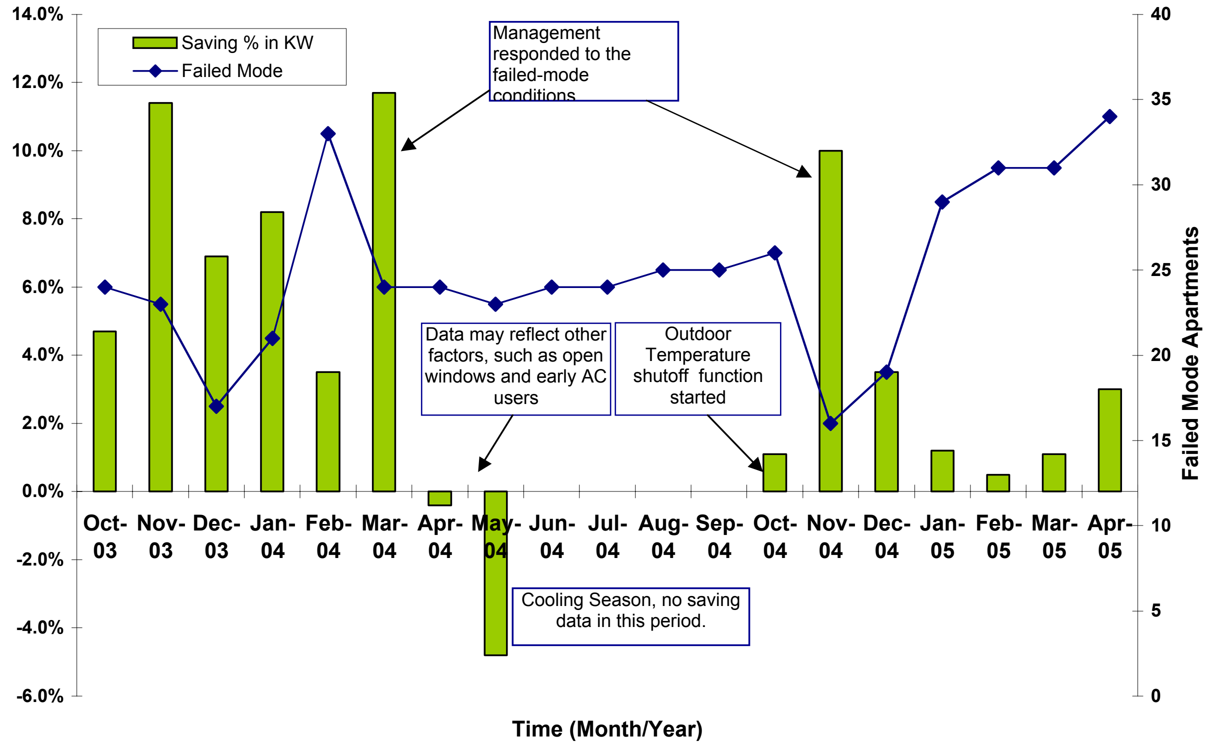
"Failed-mode" devices are used in Figures 2 and 3 as a proxy indicator for resident and staff acceptance of the new control system. Failed-mode devices are control panels in apartments

[1] Savings for both projects are calculated by regression of electrical consumption, KWh/day on the vertical axis, against heating degree days per day on the horizontal axis, for the billing period. Savings are the difference between the billed quantity and what would have been used based on the best-fit line for the pre-retrofit performance multiplied by the number of degree-days in the billed period. Baseload is separated from the temperature-sensitive heating load.



that are not communicating properly. Failed-mode units at the beginning of each project's operation are attributable to lack of access (to initialize the devices) or device communication problems. Through on-going service and analysis during the course of the project, we confirmed that later-developing failed-mode instances could most commonly be traced to tampering, either by residents or by maintenance staff disabling devices in response to complaints. Figures 2 and 3 show very different patterns of Fail-Mode experience at the two sites for the same technology.

Figure 2. Electric Heat Pilot Building No. 1, 169 Apartments Savings vs. Failed-Mode Apartments (Tampering Proxy)



source: AEA

Electric Heat Pilot Site No. 1

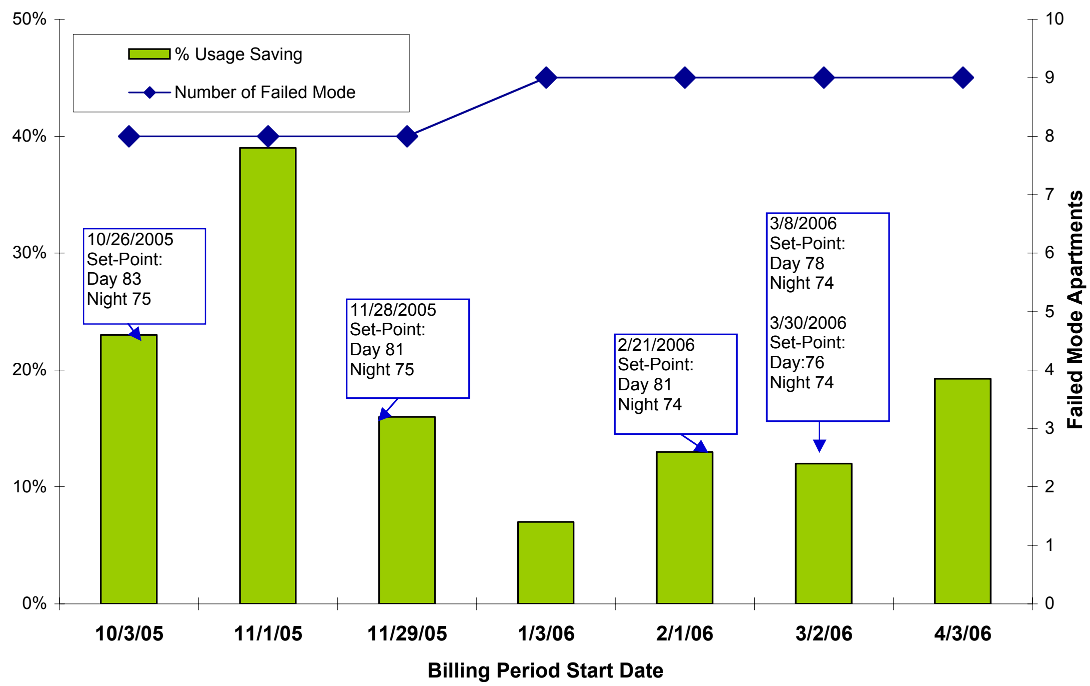
Upon completion of the first site's installation, management insisted on a uniform set-point of 74 degrees F despite our advising a gradual approach. Figure 2 shows dramatic savings in the first months of operation with increasing "failed-mode apartments" and decreased project performance, especially in the second year of operation. There are 169 apartments fitted-out with control out of 202 apartments on the master meter.

On-site staff did not see the control system as a useful tool and resisted training and daily use for monitoring. Of the many features of the control tool, on-site management learned best how to reset an individual apartment set-point to respond to complaints. For this use we suggested modest upward resets, later to be followed by very gradual resets downward. But we only observed the first part of this process to take place.

During the first year at Pilot Site No. 1, there was enough resident response to obtain higher apartment temperatures that we became able to remotely identify, by scanning simultaneous plots of apartment temperature and electric use, occurrences of ice on sensors, use of gas stoves and of plug-in electric heaters, This is reported on separately (Harris et. al. 2005). While we did not quantify the aggregate number of these occurrences, they did suggest to us significant attention paid to the control panels by residents, supporting our hypothesis that most fail-mode instances could be traced to tampering.

We suspect but are unable to document on-going upward drift of both set-points and temperatures. Unfortunately, our data management design was lacking for a research approach to the project. Our tools proved deficient for developing temperature data into useful, reportable trend information. Development work is on-going to have tools that will allow us to query, analyze and report on the acquired and warehoused data (Huang, forthcoming).

Figure 3. Electric Heat Pilot Building No.2, 535 Apartments Savings vs. Failed-Mode (Proxy for Tampering) and Settings



source: AEA

Electric Heat Pilot Site No. 2

The second site, put into operation two years later, tells a different story, based on a more patient approach. Management accepted a start-up strategy of first implementing just a night setback while leaving daytime set-points high (low-80's). On-site operating staff was quite positive in attitude from the outset, interested in learning the system interface and capabilities and willing to use the system for daily scanning. Early complaints were minimal. Acceptance level, by both residents and operating staff, has been high. Figure 3 represents this story through the absence of tampering indicated by the low and stable number of failure-mode instances. There are 535 apartments fitted out with control out of 550 apartments on the master meter.

It should be noted that this project, unlike the previous one, also included replacement of windows on a site marked by strongly varying wind exposure from ocean frontage. The new windows may have played a role in resident satisfaction and acceptance. We hypothesize also that it accounts for the very high percentage savings in November: with decreased window heat loss and drafts, heating could be kept off much further into the heating season than before.

Following initial acceptance the project is now positioned to begin gradually reducing set-points to where we will see significant amounts of daytime switching (temperature limiting). Figure 3 also shows that towards the end of the first heating season we worked with building staff in experimenting with lowering day-time set-points. Although the set-point changes were implemented more precipitously than we would have liked, there was no report of complaint. An increment in percentage savings is apparent in the last recorded month.

Conclusions

IT-based control technologies do enable a new approach to temperature change projects. With new-found data availability, practitioners can better understand building thermal dynamics, design control solutions, and introduce them gradually, so that the likelihood of resident acceptance is improved. Our early experience and data suggest preliminary confirmation of the hypothesis that gradual temperature adjustment improves project acceptance by residents. We have also seen that acceptance by the on-site building operators is an important variable in project success.

Several implications follow from this improved process for temperature control change. There is an extended, performance-based process by contractors and building operators that must follow the installation of new control and data-acquisition equipment. This new process is data-intensive and new tools are necessary for utilization of the data. Contractors and operators must master new concepts, skills, and adjust their routine practices. Training is important and must be planned into the process. It may prove most effective for data management and supporting functions to be handled by an outside specialist service bureau that would be engaged in the long-term monitoring of building performance along side of the on-site operators.

We suggest that our experience in NYC may have relevance to work in other kinds of housing stock, climatic conditions, and HVAC priorities. In an era of rising fuel costs and constrained electric capacity, temperature control will be an important strategy. Local controls with short feedback loops will certainly play a role. But the new dimension of intelligence from IT-based data acquisition and control will provide feedback at a broader level and to more parties to the process that can support a combination of system-wide optimizations and resident acceptance of new temperature regimes.

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