**Title**
Mixed-Mode Ventilation and Building Retrofits

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# MIXED-MODE VENTILATION AND BUILDING RETROFITS

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## 1. BACKGROUND

Is there a place for improving passive performance in existing buildings? Even in naturally ventilated buildings, it is relatively common during a retrofit to add new cooling and ventilation equipment to address increased internal gains, indoor environmental quality concerns, and in some cases occupant expectations. Mixed-mode strategies, which combine natural ventilation and mechanical cooling to meet peak loads, offer the possibility of using existing building features to enhance passive performance, as demonstrated by a growing number of retrofit projects. Whether air conditioning is being reduced or minimized, these designs often involve a compromise between the need for new systems, a desire to retain original operable windows, and the goal of being "green." As more attention is directed towards deep energy reductions in existing commercial buildings, understanding how designers have made decisions to integrate operable windows with new systems offers insights into the opportunities and risks associated with this type of project.

## 2. LITERATURE REVIEW

Understanding the potential for natural ventilation in the existing building stock requires a broader understanding of the state of the existing building stock and the types of interventions that are conducted in the current market. As a part of this report we reviewed available documents on market factors, design guidelines, case studies and other research that is relevant to the practice of enhancing natural ventilation as a means of avoiding mechanical cooling in existing buildings.

### Market Context

Environmental awareness and recession woes have transferred focus to existing buildings across policymaking, design, construction, and real estate sectors. According to recent market surveys, Projects that involve improvements with an environmental benefit (energy, water, comfort) are estimated to comprise 5-9% of the retrofit and renovation market in 2009, growing to around 25% in 5 years (McGraw Hill 2009).

A recent broad assessment of energy opportunities in the existing commercial retrofit market makes a distinction between "simple" energy efficiency retrofits, which provide 10% savings at a cost of $1/s.f.; and "substantial green retrofits," which define projects that aim for 40% savings at a cost of $10-$30/s.f. (Pike 2009). The report concludes that the market for substantial green retrofits will not grow rapidly without a larger program to improve occupant satisfaction. In other words, energy reduction by itself is not strong enough to drive substantial changes to energy use in existing commercial buildings. Seen another way, substantial savings opportunities exist for projects in which other priorities are more likely to take precedent. Although energy benefits may result from bringing the building and its systems up to code and installing more efficient equipment, it is difficult to assess the environmental impact since projects are often correcting for deficiencies in comfort or environmental quality that more often than not lead to increasing system components, fan energy, and electronic equipment (Bordass, pers. comm. 2009). In the LEED rating system, changes that substantially alter a building's operating strategy are likely to be considered major renovations (changes planned for more than 50% of existing space or that displace more than 50% occupants) and treated under LEED for New Construction (NC). Until mid-2009 LEED NC did not require verification of operating performance, and the system involves different methods of accounting for energy performance compared to LEED for Existing Buildings Operation and Maintenance (EBOM). The question becomes what kinds of "substantial" retrofits are most likely to provide both deep, sustained energy reductions while correcting for the deficiencies of aging or outdated buildings.[1]

In the U.S., there is very little data available on what types of improvements are most common in existing buildings and how decisions are made to weigh options that impact energy use. Beyond operating performance, building improvements can be driven by any of the following (compiled from Brand, 1994; University College, Dublin, 1997):

- Degradation (decay of structure, envelope, services, or finishes)
- Re-programming (change in ownership, tenancy)
- Change in service requirements (technological development)
- Indoor environmental quality (temperature, health, noise, ease of interaction)
- Company image
- Compliance with policies (building codes, emissions standards)
- Increase in leasable space
- Planning or tax regimes that make demolition and rebuild less practical
- Architectural conservation/restoration

Changes to existing commercial buildings can be understood in terms of the regular retrofit cycles various components undergo. For instance, although authors' estimates vary, systems and appliances tend to be replaced on a cycle of 7-15 years, and non-structural façade elements every 15-50 years. (Mulligan and Steemers, 2002). Most construction activity in existing buildings takes place to interior components in response to tenancy changes; however, modifying windows is also relatively common – roughly 20% of projects in California – according to a 2002 survey (Dohrmann et al. 2002). These trends vary regionally;

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[1] How to maximize long-term economic, environmental and occupant benefits in a retrofit project is the subject of a large research effort in Europe devoted to applying multi-criteria analysis to retrofit options (Flourentzou and Roulet, 2002; Rey, 2004; Diakaki et al., 2009). In 2002, The European commission developed TOBUS – Tool for Office Building Upgrading Solutions. In contrast to energy service models used in the U.S., TOBUS involves a site inspection, indoor environmental quality questionnaire, and software analysis tool that codes the results and generates options based on a series of parameters: physical degradation, functional obsolescence, energy use, and IEQ. (Caccavelli and Gugerli, 2002).

in a similar survey of retrofits conducted in Canada from 1998-2003, changes to the exterior only occurred in 5% of buildings (Ryan and Young, 2004). Cosmetic façade changes are also more frequent in newer, suburban commercial developments. (Garreau, 1991)

Table 1. Most Common Changes made to Existing Buildings (Calif.)

| Building Component Changed | Percent of Cases |
|---|---|
| Interior Components Changed | |
| Lighting | 76% |
| HVAC distribution system | 72% |
| Lighting + HVAC distribution | 65% |
| Interior partitions | 60% |
| Lighting + Interior partitions | 52% |
| HVAC components | 46% |
| Lighting, HVAC + Interior partitions | 42% |
| Power distribution system and components | 37% |
| Exterior Components Changed | |
| External windows, skylights and doors | 19% |
| Roof system | 10% |
| Shell structure, ornamentation and façade elements | 9% |
| Total cases (n) | 341 |

Source: Dohrmann, et al 2002, based on survey of 100 “recently renovated” buildings

In a McGraw Hill study conducted in 2009, about 60% of the 738 “green” retrofit and renovation projects surveyed improved the efficiency of the building’s envelope, usually by installing more efficient windows and/or improving insulation. Over 50% of projects reported incorporating occupant comfort measures such as increased ventilation rates to meet ASHRAE 62, demand-controlled ventilation, and the addition of individual comfort controls. These statistics underscore the increased attention paid to indoor air quality and thermal comfort control in building retrofits and also how substantial absolute energy reductions are difficult to determine and probably uncommon.

## Building Retrofits and Natural Ventilation

The main reasons why natural ventilation might be used in a retrofit as a method of avoiding or reducing air conditioning are as follows (from Kendrick, Martin and Booth 1998). It should be noted that this assessment is based on cases observed in the UK, where a larger percentage of air-conditioned buildings have pre-existing operable windows. Our review of recent projects indicates that cases of installing operable windows or introducing natural ventilation into a previously sealed, air conditioned buildings is virtually non-existent. But the theoretical potential is similar:

1. **Basic replacement (20-25 years)**. Natural ventilation would reduce operations and maintenance costs, improve occupant satisfaction, increase leasable space
2. **Replacement/renovation of the building exterior is necessary.** Increasing passive performance to be “green” may increase occupancy and lease rates
3. **Adaptive re-use**. The building is stripped down to its fundamental structure and treated similar to a new construction project
4. **Unacceptable conditions in the building due to increased heat gains.**

If improving the passive performance of a building is a priority of the owner, natural ventilation can be considered as an option in any building project only following an assessment of the predicted internal gains, thermal storage capacity, and outdoor air quality at the site (including noise). A scoring system can be applied to determine the level of renovation that is required for dealing with heat gains with the minimum necessary mechanical equipment (Kendrick, Martin and Booth 1998). As a rule of thumb, there are a number of advantages and disadvantages characteristic of certain building vintages, as follows.

Table 2. Generalized Opportunities for Natural Ventilation in Existing Buildings

| Period | Construction Method | Advantages | Disadvantages |
|---|---|---|---|
| Pre 1900 | Masonry | High Ceilings<br>Tall Windows<br>Good Natural Light<br>High Thermal Mass | May be listed building<br>Structural partitions = inflexible space, poor circulation |
| 1900-Pre WWII | Masonry, concrete or steel frame | May have high ceiling<br>Narrow Floor Plate | May be listed building<br>Structural partitions = inflexible space, poor circulation |
| Late 1950s/1960s | Steel frame or reinforced concrete, curtain wall | Narrow floor plate<br>Open plan layout | Low floor-floor height<br>Large glazed area<br>Low floor loading<br>Relatively lightweight |
| 1970s Office | Steel frame or reinforced concrete | Larger floor-floor height than 1960s (for services)<br>Open plan layout | Deep plan<br>Lightweight construction |

Source: Kendrick, Martin and Booth (1998)

The multitude of environmental and human considerations that enter into designing and controlling a natural ventilation system that works has led to a wide range of design strategies that allows the least mechanical control possible. The following list attempts to show the range of common low-energy ventilation and mixed-mode strategies in order of increasing mechanical components (Holmes, 2000). In a retrofit, how far up the scale to go is limited by cost and also related to a building's vintage and construction characteristics as well as code restrictions and the priorities of the owner.

Simple natural ventilation with operable windows
Natural ventilation + a control strategy
Natural ventilation + mechanical ventilation (stage 1 or hybrid ventilation)
Limited cooling + displacement ventilation
  Often combined with stage 1 and called "mixed-mode" (stage 2 hybrid ventilation)
Limited cooling, displacement ventilation + passive cooling devices
Full air conditioning

In a simulation-based study, BRE (2000) applied a range of low-energy ventilation strategies in four generalized UK office building types[2] and found that some form of natural ventilation could be introduced at different levels of renovation in both naturally-ventilated and air-conditioned buildings to match available budgets; in other words, there was a mixed-mode approach appropriate and cost-effective for any office building type. This conclusion exemplifies the "best of both worlds" attitude shared by mixed-mode advocates, in which mechanical and natural conditioning are simply scaled against one another to maximize the benefits of both in the face of various design constraints. The retrofit solutions that were applied to each office building type are summarized in the table below.

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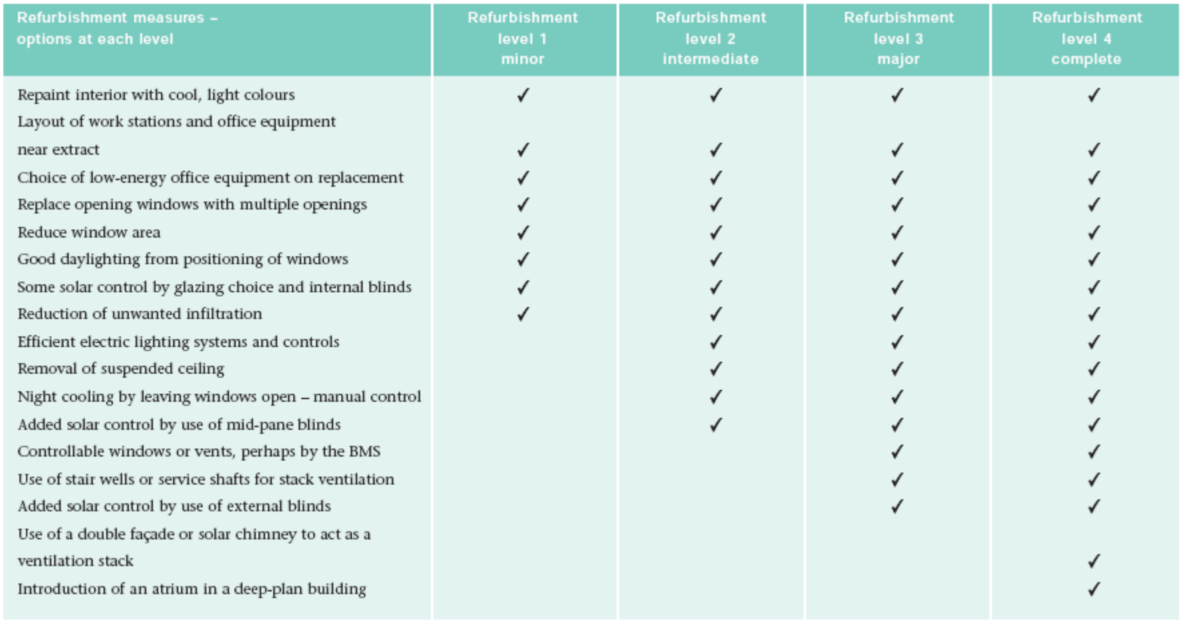
[2] The typology was based on a survey conducted that same year: ***Energy Efficiency Best Practice programme.*** Energy Consumption Guide 19, 'Energy use in offices'. DETR, London, 2000

Figure 1. Measures associated with Passive Refurbishment Options, BRE 2000



| Refurbishment measures – options at each level | Refurbishment level 1 minor | Refurbishment level 2 intermediate | Refurbishment level 3 major | Refurbishment level 4 complete |
|---|---|---|---|---|
| Repaint interior with cool, light colours | ✓ | ✓ | ✓ | ✓ |
| Layout of work stations and office equipment near extract | ✓ | ✓ | ✓ | ✓ |
| Choice of low-energy office equipment on replacement | ✓ | ✓ | ✓ | ✓ |
| Replace opening windows with multiple openings | ✓ | ✓ | ✓ | ✓ |
| Reduce window area | ✓ | ✓ | ✓ | ✓ |
| Good daylighting from positioning of windows | ✓ | ✓ | ✓ | ✓ |
| Some solar control by glazing choice and internal blinds | ✓ | ✓ | ✓ | ✓ |
| Reduction of unwanted infiltration | ✓ | ✓ | ✓ | ✓ |
| Efficient electric lighting systems and controls |  | ✓ | ✓ | ✓ |
| Removal of suspended ceiling |  | ✓ | ✓ | ✓ |
| Night cooling by leaving windows open – manual control |  | ✓ | ✓ | ✓ |
| Added solar control by use of mid-pane blinds |  | ✓ | ✓ | ✓ |
| Controllable windows or vents, perhaps by the BMS |  |  | ✓ | ✓ |
| Use of stair wells or service shafts for stack ventilation |  |  | ✓ | ✓ |
| Added solar control by use of external blinds |  |  | ✓ | ✓ |
| Use of a double façade or solar chimney to act as a ventilation stack |  |  |  | ✓ |
| Introduction of an atrium in a deep-plan building |  |  |  | ✓ |

Source: [BRE] Building Research Establishment Ltd. 2000. "Comfort without air -conditioning in refurbished offices – an assessment of possibilities." New Practice Case Study 118. . UK Department of the Environment, Transport and the Regions' Energy Efficiency Best Practice Programme

Numerous guidelines for developing the most appropriate design strategy are available to designers. Like the above simulation study, most guidelines focus on how to balance the array of technical and architectural considerations involved in generating an appropriate strategy. However, the nature of the human activities that the building houses and the priorities of the client may go the farthest in determining the level of natural ventilation incorporated by the design.

| | |
|---|---|
| CIBSE, 2000<br>*Mixed-mode ventilation*,<br>Applications Manual AM13<br>See also:<br>CIBSE AM10, *Natural ventilation in non-domestic buildings* | This comprehensive resource is applicable to both new and retrofit mixed-mode projects. It explains the argument in favor of using mixed-mode, points out the major limitations, and outlines a process for navigating available design options. |
| Andrew Martin and Jason Fitzsimmons, 2000<br>*Making natural ventilation work*<br>BSRIA Guidance Note, July, 2000 | Based on discussions with facilities personnel, this guide reviews the most common operational failures in naturally ventilated buildings and provides design solutions to mitigate or avoid them. Strategies are applicable to new designs as lessons learned or to existing buildings with similar operational issues. |
| Chris Kendrick, Andrew Martin, William Booth, 1998.<br>*Refurbishment of air-conditioned buildings for natural ventilation*<br>BSRIA Technical Note, August, 1998 | Provides a design methodology and grading system for assessing the potential for natural ventilation in renovation projects based on existing features and extent of intervention. |
| University College Dublin. 1997.<br>*Solar Energy in European Office Buildings – Technology Module 7: Retrofitting.* | Describes the scenarios in which natural cooling and ventilation, as well as passive solar strategies, are feasible to introduce during a building retrofit |

| | |
|---|---|
| Building Research Establishment Ltd., 1995. *Avoiding or minimizing the use of air-conditioning – a research report from the EnREI Programme*<br>General Information Report 31 | Guidelines for design decisions regarding the control strategy and/or operational features of a naturally-ventilated or mixed-mode building are extracted from monitoring results for 12 naturally-ventilated commercial buildings in the UK |
| Erin McConahey, 2008<br>"Mixed-Mode Ventilation: Finding the Right Mix"<br>*ASHRAE Journal*, September 2008 | Presents an overview of ASHRAE standards applicable to spaces using natural ventilation and proposes an early stage decision-making methodology |
| Axley et al. 2002<br>"An Approach to the Design of Natural and Hybrid Ventilation Systems for Cooling Buildings" | Proposes a combination of tools to provide accurate analysis through the many stages of design (new or major renovation):<br>- Climate suitability analysis,<br>- Loop equation design method, and<br>- Multi-zone, coupled airflow-thermal analysis |

**Studies in Real Buildings**

In reality, factors that determine the right low-energy or passive approach depends on common practice, the experience of the design team, client expectations, and codes, just as much (if not more) than site and practical constraints. Discreet renovation features tend to be less critical than how the building manages automated and manual components. A review of both new and retrofit mixed-mode buildings finds a broad continuum of control strategies, each associated with its own unique performance implications. (Brager, Borgeston and Lee 2007) Mixed-mode designs are particularly sensitive to tradeoffs among design goals and cost; comfort and energy use; and system accuracy and robustness.

In general, available case studies have shown that it is possible to provide comfort in a building retrofit without resorting to full mechanical ventilation and cooling, although the number of papers reinforcing the hypothetical feasibility and benefits tend to outweigh the number of documented cases. Real mixed-mode retrofit projects are documented in IEA Annex 35 Hybvent project (hybvent.civil.auc.dk); Kendrick, Martin and Booth, (1998); Brager, Borgeson and Lee, 2007; Burton, Bordass and Buckley, 1994; and an ongoing survey conducted at CBE (Section 3).

In the 1990s, The British Research Establishment (BRE) (under the Energy Efficiency Office Best Practice Programme) conducted a series of studies on methods for avoiding new air-conditioning. A review of the commercial office retrofit market in the UK (Burton, Bordass and Buckley, 1994) summarized the kinds of passive retrofits taking place at the time (both for daylighting and natural ventilation) and determined the following passive retrofit scenarios based on known projects:

A. Build-out and minor alterations to interior (day-lighting and commissioning only)
B. Window or façade replacement plus minor interior alterations without strategic change
C. Major renovation, conversion or addition involving strategic change (i.e. interior reconfiguration)
D. Removal of air-conditioning in shallow-plan office building
E. Removal of air-conditioning at perimeter in deep-plan office building (zoned mixed-mode)
F. Other mixed-mode system in what remains a sealed, air-conditioned office building (risky)

This typology is based on single precedents, and the cases representing the most aggressive categories, E and F, were not completed projects. However, other programs in Europe have made attempts to demonstrate feasible options for improving the passive performance of post-war office building stock.

For example, the Hybvent research project, funded by the International Energy Agency (IEA Annex 35), featured three mixed-mode retrofits out of a total of 12 pilot retrofit studies conducted between 1998 and 2002. These included The PROBE building Limelette, Belgium (built 1975); the Wilkinson Office Buidling in Sydney Australia (built 1986); and the Tanga School in Falkenburg Sweden (built 1968). Each report includes detailed performance data from before and after the retrofit, in terms of both occupant comfort and energy use by end use. All cases show improvements in both comfort and fan and/or cooling energy use.  These cases are valuable because they focus on how occupant behaviors and attitudes adapted and responded to the enhancement of passive systems through new control strategies and operable features, in addition to documenting changes in the building's absolute energy consumption.

More recently, the Carbon Trust has funded a series of showcase "passive refurbishment" projects in order to document the challenges and opportunities encountered in low-carbon retrofits. The most substantial and successful project is Ashburton Court in Winchester, UK. During a modernization of a 1960s sealed, deep-plan commercial office complex, architects converted the building from pure mechanical cooling to a passively-cooled mixed-mode design by adding rooftop wind troughs to promote wind-driven cross-ventilation throughout the office building. Occupancy was disrupted but not changed, and pre and post occupant satisfaction data was collected in addition to energy performance. The case study was intended as precedent for other buildings of similar construction type that are in need of re-cladding and/or modernization.

A common finding in retrofit projects that attempt to reduce or avoid air conditioning (e.g. BRE 1995; Hybvent 2000; Buhagiar 2009; Fisher, 2008) is the idea that improving passive performance is very sensitive to assumptions designers make about how the control strategy is implemented and operated in practice. Field studies have revealed that thermal controls often do not operate as anticipated, either because their sophistication outweighs the knowledge of their users or because the use of manual features inadequately accounts for conflicts inherent in how occupants must manage daylight, glare, and ventilation. (Aggerholm 2002; Bordass and Leaman 1993).

In a fairly recent look at the potential of passive retrofit measures (Barlow & Fiala 2007) the authors posit that "spatial or temporal control strategies" (i.e. more automated mixed-mode control strategies) should not be relied upon to maintain comfort *in building retrofits*. Rather,

> The inclusion of active adaptations such as opening windows, occupant control of external and internal blinds, localized switching … need to be made central to refurbishment strategies as measures perceived as contributing to improved occupant comfort while reducing buildings' energy consumption and CO2 emissions. (Barlow & Fiala 2007)

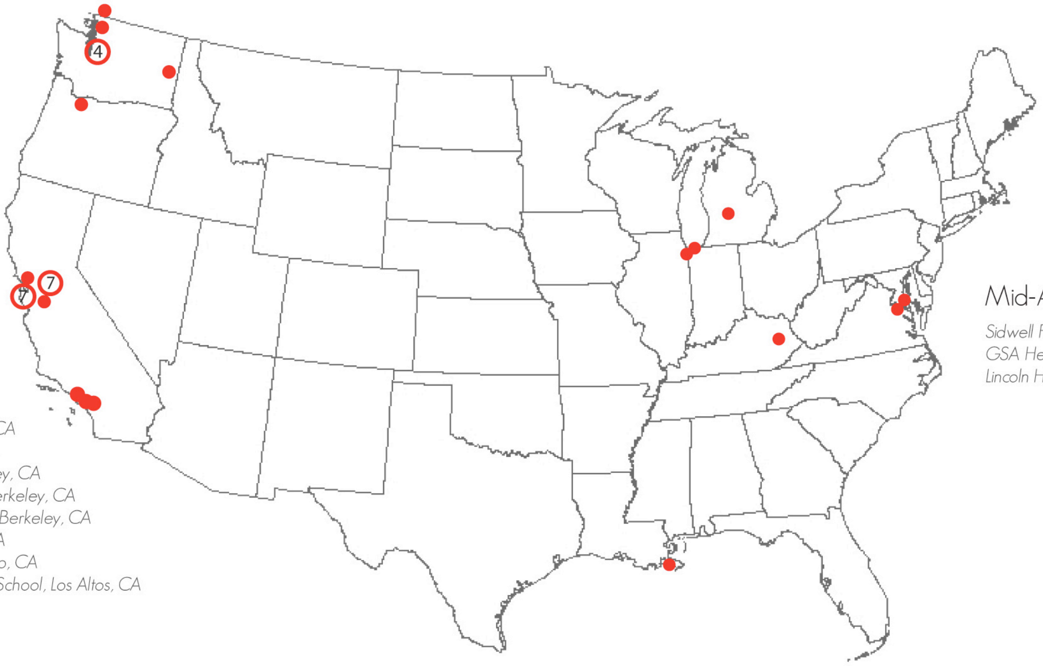
The authors go on to recommend further research into the use of operable features in shared office settings, and the need to better understand the relationship between individual adaptive preferences and the overall operating patterns of the building as conceived by its designers.

## 3. CBE DATABASE OF MIXED-MODE RETROFIT PROJECTS IN THE U.S.

Listed below are 33 non-residential retrofit projects, including 19 in California, in which natural ventilation was maintained and enhanced in a retrofit. Sources for this case list include interviews with architects, design engineers, development companies, consultants and property management firms operating in California or knowledgeable of historic or energy-efficient retrofit projects, as well as a review of USGBC, DOE, Building Green and CBE high performance building case studies.

The purpose of compiling this database is to understand the scenarios in which natural ventilation is most commonly retained/introduced in existing buildings in the United States. The projects are classified based on the kind of retrofit—that is, the reasons for the retrofit and the extent of changes that were made—as well as the kinds of changes that most commonly accompany a move toward mixed-mode conditioning, such as the type of HVAC system, the introduction of new ventilation pathways, changes to finishes, and the sophistication of controls provided. The scenarios are described in the following sections and include detail about specific representative projects where available, based on interviews with design team members.

Figure 2. Regional Distribution of Retrofit Cases



Pacific Northwest

*Jean Vollum Natural Capital Center, Portland, OR*
*Compton Union Building, WSU, Pullman, WA*
*Miller Hall, WWU, Bellingham, WA*
*Nathan Hale High School, Seattle, WA*
*Joseph Vance Building, Seattle, WA*
*Savery Hall, UW, Seattle, WA*
*Clark Hall, UW, Seattle, WA*
*BPA Annex, Vancouver, BC*

Upper Midwest

*Herman Miller Building, Zeeland, MI*
*Chicago Center for Neighborhood Technology, Chicago IL*
*Center for Green Technology, Chicago, IL*

N. California

*654 Minnesota, S.F., CA*
*Flood Building, S.F., CA*
*Thoreau Center, S.F., CA*
*Presidio Building 38, S.F., CA*
*S.F. Friends School, S.F., CA*
*Pier One Building, S.F., CA*
*50 UN Plaza, S.F. CA*
*StopWaste.org, Oakland, CA*
*Oakland City Hall, Oakland, CA*
*436 14th Street, Oakland, CA*
*Berkeley Civic Center, Berkeley, CA*
*Naval Architecture Building, Berkeley, CA*
*Berkeley YMCA Teen Center, Berkeley, CA*
*2020 Milvia Ave., Berkeley CA*
*Montgomery Hall, San Anselmo, CA*
*Georgina Blach Intermediate School, Los Altos, CA*

Mid-Atlantic

*Sidwell Friends School, D.C.*
*GSA Headquarters, D.C*
*Lincoln Hall, Berea, KY.*

S. California

*UCLA Kinsey Hall, Los Angeles, CA*
*NRDC Offices, Santa Monica, CA*
*Navy Building 850, Port Hueneme, CA*

South

*Lavin-Bernick Center for University Life, New Orleans, LA*

Figure 3. Drivers for Retrofit

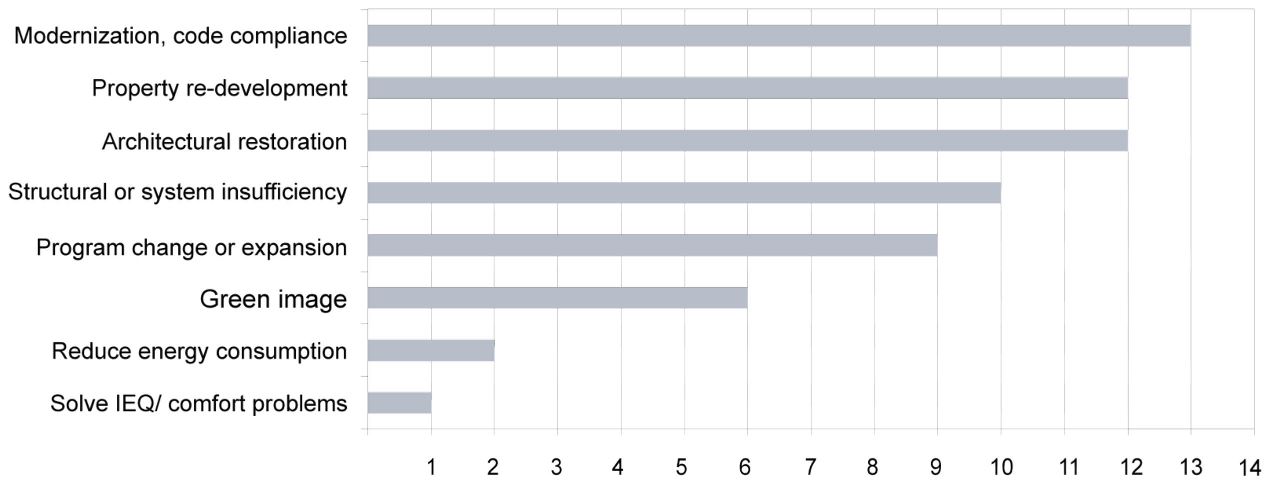
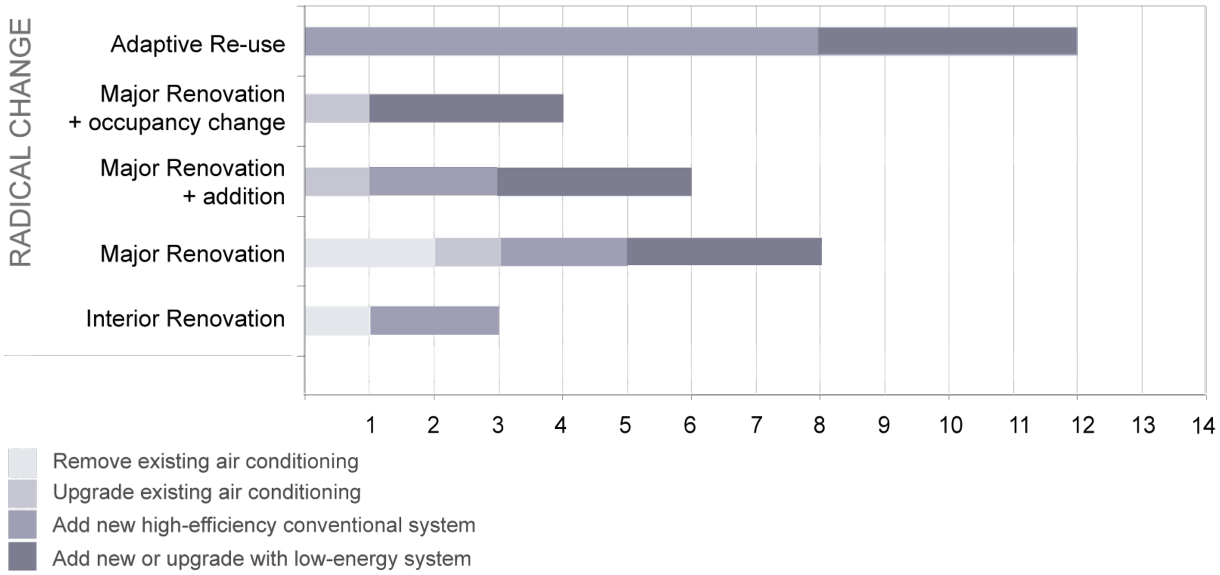


Figure 4. Distribution of Cases by Retrofit Classification



***Extent of Retrofits and Common Drivers***

As shown in Figure 4, we categorized projects according to the extent of changes made to the existing building and how the cooling strategy was affected. Note that all but three projects underwent what we are calling “radical change;” that is, the building was essentially gutted and all systems replaced. This is related to the fact that the majority of mixed-mode retrofits are driven by long-term property investment goals such as modernization, rehabilitation or expansion (Figure 3). We identified four general “radical change” scenarios. The single most common scenario for mixed-mode retrofits is to install or upgrade cooling systems during the **adaptive re-use** of an existing building with operable windows in order to salvage and/or redevelop the property. This category is set apart by the fact that the cost-effectiveness of the projects is likely to be determined relative to demolition and/or new construction, which is often favorable[3].

The term **"major renovation"** refers to those projects in which the building was retained for approximately the same use; that is, the design strategy was to enhance the existing purpose of the building even if the building was radically altered or gutted. As shown in Figure 4, major renovations are often driven by a programmatic changes that affected the nature of the occupant group or the building activities (for example, accommodating a new academic department), and comparing the performance before and after the renovation is relatively meaningless (even if the data was available, which it isn't).

The three projects that are classified as **interior renovations** are all historic rehabilitation projects that entirely preserved the character and layout of the interior space and caused less than a total displacement of occupants. Two of the projects (San Francisco's Flood Building, and Oakland's Historic Central Building) represent a typical scenario in which, during a standard building upgrade, heating and lighting equipment are upgraded along with, less commonly, the efficiency of the building envelope. Opportunities to control solar gains are limited due to façade preservation restrictions. Unless concerns about comfort are vocalized, sealing the windows isn't part of the discussion. Conventional air conditioning is usually added to serve the tenants that request or require it (usually ground-floor retail or IT-intensive tenants) but not deemed necessary throughout the building. *Our review did not find any projects in which minor enhancements to the interior of a building explicitly prevented the installation of new air conditioning as suggested by BRE (1998).*

For the 11 projects (including 8 major renovations) that featured no major changes in use, how the cooling systems were changed varied greatly. Specific cases are described below.

***Removal of air conditioning***

Three projects, all historic rehabilitations, featured the removal of previously added air conditioning in order to return the building to being natural ventilated. Contrary to the theoretical potential presented in the literature, we found no cases in which mechanical cooling was removed in a building that was not originally designed for natural ventilation. However, removal of air conditioning can be feasible without a major gutting or alteration of the facade. At the Joseph Vance Building in Seattle, WA, the property developer decommissioned window air conditioning units gradually upon tenant turn-over, adding light interior finishes, solar control and ceiling fans. The two other cases required more radical interventions. The Berkeley Civic Center renovation removed window units and added new stack ventilation pathways, fans, and a night flush system to maintain passive cooling. New packaged units were added to serve a new IT center and a top floor penthouse. Montgomery Hall at San Francisco Theological Seminary also removed pre-existing air conditioning units during a major gut renovation and historic seismic rehabilitation.

***Adding new cooling equipment***

More commonly, building retrofits that allow both operable window use and mechanical cooling feature the addition of high-efficiency conventional all-air systems or alternative low-energy cooling systems where no cooling system existed before. This was the case in 16 of the major renovation projects, 9 of which involved the concurrent use of windows with less conventional systems such as radiant panels, chilled beams, ground-source heat pumps, ice storage chillers, under-floor air delivery, and ductless air conditioning.

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[3] Advantages of re-use over new build include potentially lower capital costs, shorter completion times, and avoidance of planning constraints. Kendrick, C., A. Martin, Andrew; and W. Booth. 1998. *Refurbishment of Air-conditioned Buildings for Natural Ventilation.* The Building Services Research and Information Association. Technical Note TN 8/98. Berkshire, United Kingdom.

An interesting example is provided by Savery Hall, a large faculty office and classroom building on the University of Washington campus in Seattle. Driven by the desire to be as sustainable as possible during a recent massive gut renovation and modernization, the design team was dedicated to enhancing natural ventilation to avoid the addition of air conditioning. Initially, the design for Savery Hall featured fan-assisted ventilation towers and automated air intakes to prevent a large air-handling system. However, the actuators were value-engineered out of the design, leaving the windows to be manually controlled. Due to the building's orientation and restrictions on exterior solar control, the design team could not guarantee comfort during peak summer days and decided to incorporate a small VAV system with variable refrigerant flow units for cooling and heating. To minimize the operation of the VRF in cooling mode, red-green light indicators were also installed to encourage occupants to use their windows.

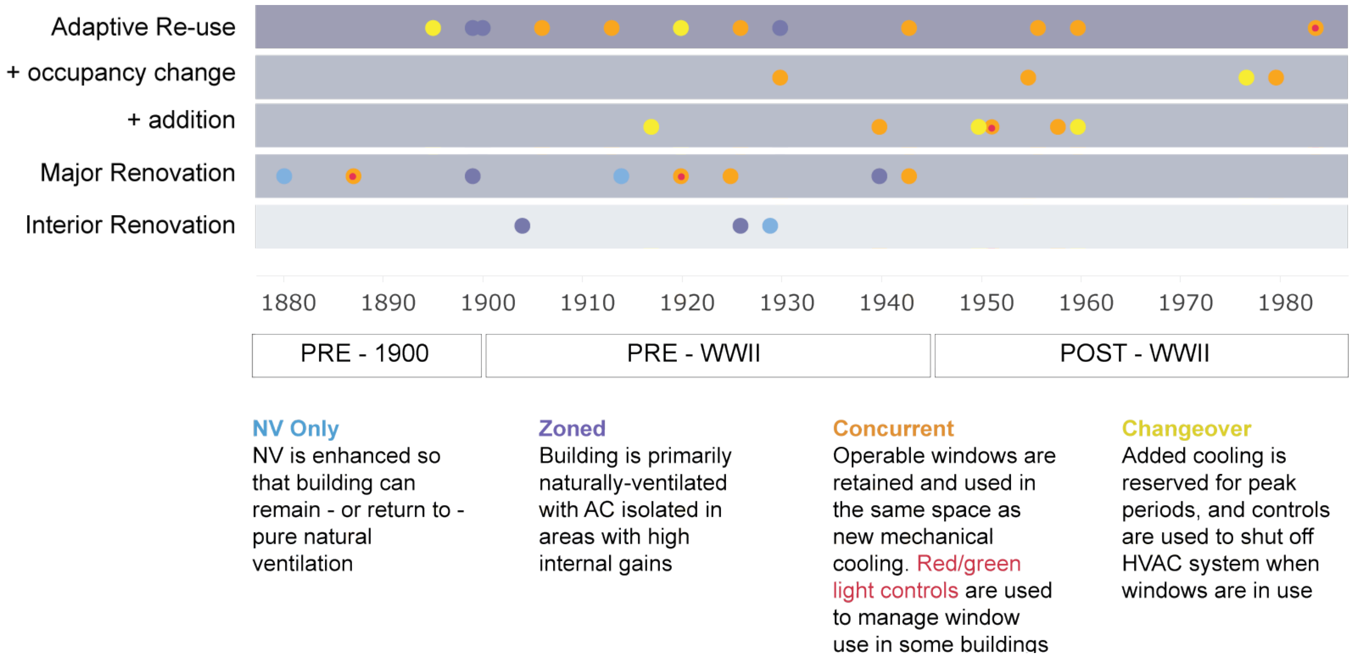
Thanks to a well-trained and involved staff, campus operations overcame the initial hurdles of adapting to the unfamiliar mechanical system. However, due to the building's large size, partitioning and variable loads, optimizing manual window use has been a challenge. A strong partnership between the designers and building managers in educating building occupants may be the most critical factor. Because occupants operate in private offices and classrooms on their own schedules, general awareness is low, and windows left open over night has been a minor problem. Whole building energy use is up 30% than what was expected, but the reason for this increase is unknown as the building was only just recently sub-metered.

### *Replacing conventional AC with low-energy systems*
In five cases, low-energy cooling was installed to replace, or partially replace, a pre-existing conventional HVAC system, most likely reducing total cooling energy. The best example of this scenario is at the Compton Union Building (CUB), a large 1950s, deep-plan student union at Washington State University in Pullman, WA. CUB's original design included operable windows, but it also was built to house a massive central air handling system. During a recent modernization project, a high priority objective was opening up the interior space, which enabled the design team to consider more expensive radiant cooling systems (radiant panels in the offices and chilled beams in the café), allowing for much less ductwork and higher effective ceiling heights. People involved in the design process cited students' ownership of the project and close involvement with the design process as central to following through with this relatively high-cost option.  In the office spaces, efficient integration of the new system with pre-existing operable windows is also managed by a signaling device (amber/green lights). No energy performance data was available for this project.

### *Mixed-Mode Control Strategies*
Figure 5 shows the projects organized by date of original construction, extent of retrofit, and mixed-mode control approach. The graphic shows a few patterns. The first is the tendency for renovations of historic buildings to remain largely naturally ventilated with added conventional air conditioning in some zones (like ground-floor retail spaces or IT rooms). Secondly, the majority of projects in all categories are relatively unsophisticated in terms of automated control, allowing the concurrent operation of manually-controlled windows with the cooling system (orange dots). As described earlier, eight of these use low-energy, often radiant, cooling systems to minimize the energy consequences of using the windows. Four of these projects use signaling systems to manage the use of windows. Five other projects (yellow dots) include the use of HVAC shut-off controls to force a change-over between modes.

No projects (excluding additions) involved automation of windows to help manage a changeover between mechanical and natural ventilation modes. The Berkeley Civic Center and Savery Hall projects abandoned installing actuators on windows to initiate a natural ventilation cycle, in favor of cheaper signaling controls.

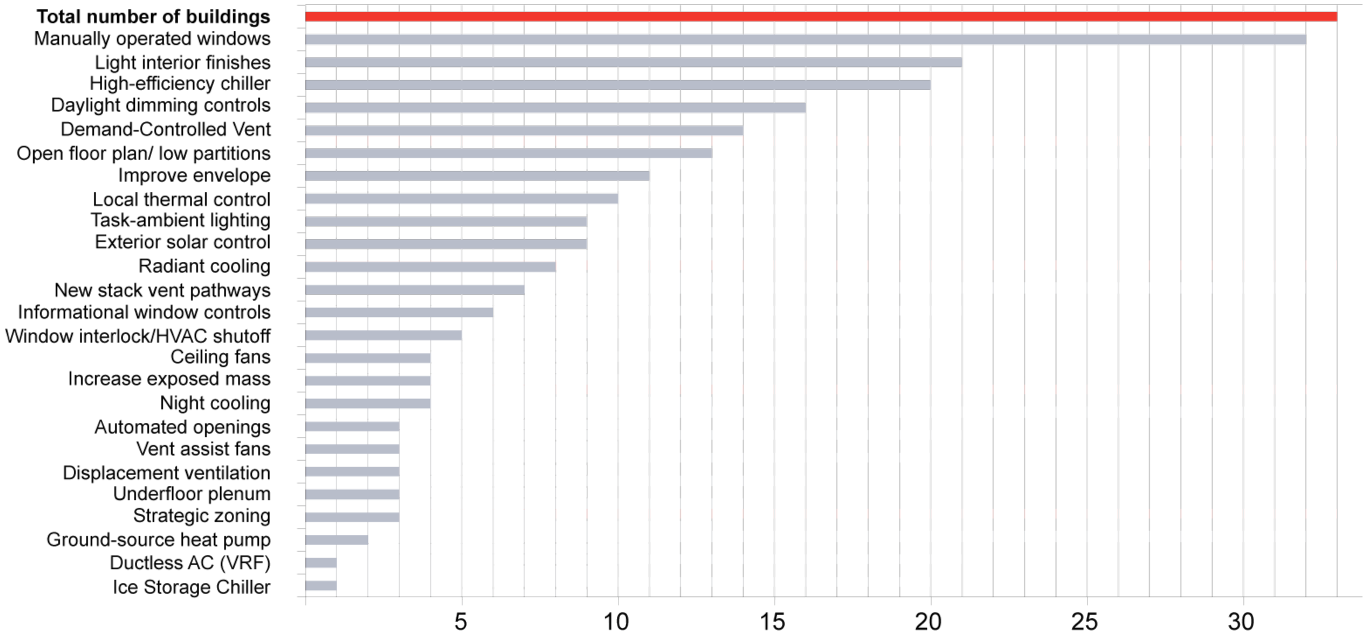
Figure 5. Projects by Construction Date, Retrofit Activity and Control Strategy



### *Additional measures to enhance natural ventilation*

Figure 6 lists measures that were taken during the retrofit to enhance natural ventilation with operable windows. These include daylighting measures, envelope upgrades, local thermal control features, layout considerations, and high-efficiency cooling and air delivery systems. Daylighting measures seem to be the most common (photo sensors and dimmable electronic ballasts, light finishes, open floor plan), while measures one might expect to be quite common in retrofits, such as the exposure of thermal mass, night flush strategies, and ceiling fans were not very prevalent. Meanwhile, the creation of new natural ventilation pathways, which might seem less practical, were fairly common, although not necessarily taken advantage of in operation. Radiant cooling was the most common technology to be coupled with operable windows in a retrofit outside of conventional air conditioning. The most common control strategy was the use of signaling devices (red/green lights, etc) to help guide occupants in managing their windows efficiently.

Figure 6. Most Common Retrofit Measures



## 4. CONCLUSIONS

Interventions to improve the passive performance of existing buildings can occur at any scale; however, designing for natural ventilation engages an array of inter-related technical and architectural considerations such that meaningful improvements are usually only feasible during more major renovations. However, because major renovations are inherently driven by other owner priorities (like seismic stability, building modernization or programmatic change), it is very difficult to assess mixed-mode design as an energy reduction strategy. Furthermore, *avoided* increases in cooling energy can in many cases be attributed to the choice of using low-energy cooling systems coupled with operable windows, not the use of natural ventilation in and of itself. Additionally, given that sophisticated automation of window control is seldom used, the extent to which the use of operable windows contributes to offsetting cooling or ventilation needs rests with the relative success the project team has in educating building users (managers and occupants) in order to promote efficient control behavior.

A look at the cases we found suggest a few themes: first, having pre-existing operable windows seems to be a pre-requisite to incorporating natural ventilation into the retrofit strategy. Secondly, inflexible material and spatial parameters often result in a simpler control strategy than was originally intended or compared to new construction mixed-mode projects. Most importantly, our interviews with design team members underscored the difficulty of generalizing what opportunities are available based on physical conditions or characteristics. This is because, by and large, the solutions that designers propose relate more to the tools and partnerships they were able to take advantage of in order to successfully advocate for natural ventilation and manage their clients' expectations. Finally, the tendency to pursue or fall back on simpler control strategies leads us to confirm findings of previous researchers who assert that the education of occupants and attempts to realistically anticipate their level knowledge and involvement regarding window use must be the focal point of evaluating success of this type of design strategy.

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