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Ventilation Technologies Scoping Study

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OVERVIEW

This document presents the findings of a scoping study commissioned by the Public Interest Energy Research (PIER) program of the California Energy Commission to determine what research is necessary to develop new residential ventilation requirements for California. This study is one of three companion efforts needed to complete the job of determining the needs of California, determining residential ventilation requirements, and determining appropriate ventilation technologies to meet these needs and requirements in an energy efficient manner.

Rather than providing research results, this scoping study identifies important research questions along with the level of effort necessary to address these questions and the costs, risks, and benefits of pursuing alternative research questions. In approaching these questions and level of effort, feasibility and timing were important considerations. The Commission has specified Summer 2005 as the latest date for completing this research in time to update the 2008 version of California's Energy Code (Title 24)

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INTRODUCTION

The goals of this scoping study are to identify research needed to develop appropriate ventilation technologies for California housing and climates. This scoping study is intended to provide a research plan for PIER to provide a technical basis for reducing energy consumption and increasing electricity reliability related to residential ventilation. The scoping study will include related issues that specifically need to be addressed by California Building Energy standards that could have an impact on technology selection and evaluation. The 2008 Title 24 Standards are the primary target for the outcome of this research, but this scoping study is not limited to that time frame. The broad intent of the scoping study (together with the other related scoping studies) is to lay the foundations for answering the question: "**Should mechanical ventilation be required in Title 24?**".

Programmatic Background

The California Energy Commission (CEC) has as a funding priority a program of Research and Development (R&D) to advance the state of knowledge on residential ventilation in California. It will support this research through its Public Interest Energy Research (PIER) program. An important goal of this effort is to identify changes to existing residential energy efficiency standards (i.e., Title 24) that can be incorporated into the 2008 standards to maintain or improve the indoor environment of new homes and reduce the energy-related impacts of these homes.

To advance the state of knowledge in this field the PIER program has established a three-part approach to the problem: 1) characterization of the indoor environments of homes built to current standards, 2) development of minimum requirements to achieve acceptable indoor air quality in future construction and 3) evaluation and development of technologies and associated descriptive algorithms for meeting minimum requirements.

These three elements act synergistically to provide the information the State needs to inform its efforts to modify Title 24. Each piece is the subject of an independent scoping study. Together these three scoping studies will lead to an integrated program of work. The goals and required timeline for these projects need to be achieved by summer 2005 to significantly inform the CEC Title 24 Standards revision. This report provides the scoping study for issue 3, the evaluation and development of ventilation technologies appropriate for California housing and climates. Each of the three scoping studies and the ways in which they interact are summarized in the following paragraphs.

Characterization Project Goals: The broad goals of the characterization project are: 1) to determine if ventilation and indoor air quality, in a population of new, production-built, single-family, detached houses built to 2001 Title 24 energy efficiency standards, are acceptable based on available guidelines for comfort and health protection and 2) to describe the influence of selected key factors, including occupant behaviors, on ventilation rates and indoor air quality in these houses. The objectives of the project are to answer a series of questions related to ventilation rates and indoor air quality (IAQ) in production-built, new, single-family, detached California homes permitted under the 2001 Title 24 standards. These questions focus on the topics of ventilation, indoor air quality and occupant behavior.

Requirements Project Goals: The broad goals of the requirements project are to: 1) determine the state of the art in residential ventilation codes and guidelines and their applicability to

California; 2) identify and resolve engineering-based issues necessary to define new minimum requirements; 3) determine how to extend engineering-based requirements with R&D to include some health protection; and 4) develop draft requirements suitable for inclusion in the 2008 version of Title 24. The objectives of the project are to focus on the technical barriers to improved residential ventilation standards and resolve these barriers. We will closely coordinate work on this project with the characterization project to identify real-world issues and problems for ventilation and indoor air quality in new construction.

Technology Project Goals: The broad goals of the technology project are to: 1) determine the state of the art in residential ventilation methods and technologies and their application to California: 2) identify and develop suitable technologies that meet new minimum requirements and are not currently used in California; 3) develop models to evaluate the full performance of potential technology using the applicable criteria of energy, ventilation, demand, etc. and 4) work with the compliance tool providers to incorporate necessary algorithms into future Title 24 compliance tools.

Project Background

This scoping study will examine the R&D and related activities necessary to produce a new generation of residential ventilation technologies appropriate for California climates. This scoping study is intended to provide a research plan that would enable PIER to provide a technical basis for reducing energy consumption and increasing electricity reliability related to residential ventilation. The scoping study will include related issues that specifically need to be addressed by California Building Energy standards that could have an impact on technology selection and evaluation. This includes issues such as:

- different approaches for new and existing homes,
- air cleaning technologies,
- different priorities for rental and owner occupied housing, and
- California-specific climates and peak loads.

Traditionally, residential ventilation in California is provided without explicit design, by leaky envelopes and window operation; designed ventilation, however, is becoming more necessary (and therefore more common) in homes. Depending on the technology used, this ventilation can represent a penalty or a savings to the energy-related systems of the State.

This scoping study will review what is known about existing residential ventilation technologies as it applies to California homes and climates. Specific issues to be addressed include IAQ performance, energy performance, peak load implications, moisture impacts, filtration/air cleaning potential and capital investment. The scoping study will identify what R&D is needed to advance these technologies for California. The scoping study is intended to assist PIER in allocating its R&D resources in this area by identifying gaps in current knowledge.

Because residential ventilation technologies will be used in the State regardless of the requirements of Title 24, this work goes beyond standards, but it is important to recognize that any relevant technology must be able to be appropriately represented within the standards. Some systems-integrated ventilation technologies, for example, can be particularly energy inefficient, but provide acceptable indoor air quality, while others can perform substantially better all around. Thus, to incorporate energy efficiency with respect to ventilation technologies, the future version of Title 24 will need to take into account information about specific technologies and their performance.

A key factor for this scoping study is the effect that an alternative ventilation standard will have on energy use calculation algorithms and compliance tools already in use by the California building industry. Addressing this issue requires interaction with the members of the HVAC engineering community who provide compliance tools for the Title 24 Standard. Future project advisory committees should specifically include representatives from compliance tool providers.

Another issue to be addressed is the potential for standards to include peak load energy demand as well as cumulative energy use. In preparing this scoping study we consider how different technologies would impact peak load ventilation requirements.

APPROACH

Title 24 focuses on cost-effective ways to minimize the energy-related impacts of providing building services such as thermal conditioning, lighting, etc. Ventilation is an energy-consuming activity and considered an end use. Providing acceptable indoor air quality is the building service provided by ventilation.

The current version of Title 24 has ventilation requirements that go beyond the model codes. Other states including Florida, Minnesota and Washington have also adopted additional ventilation requirements. Several European countries including France, Sweden, the United Kingdom and Denmark have specific ventilation requirements. In order to evaluate changes to Title 24, it is important to look at what other codes have specified, as well as what are considered best professional practice (e.g., ASHRAE Standard 62.2), when considering changes to the California code.

Ventilation is an energy consuming activity that is intended to provide acceptable indoor air quality. There is no fixed "right" amount of ventilation in the same sense that there is no fixed "right" size of furnace or air conditioner. To find the minimum requirements for thermal conditioning, one must determine the thermal load and the desired thermal conditions to be met. Similarly, to determine how much ventilation is necessary one must look at the sources of concern (i.e. pollutant load) and the desired level of indoor air quality. Selection of appropriate ventilation technologies must be made by trading off various costs (e.g. energy costs, first cost, risks, etc) with the benefits associated with the building service (e.g. health and comfort).

OBJECTIVES

There are four objectives necessary to achieve the goals of this project. These objectives include:

1) assessing the state of the art in residential ventilation technologies and strategies for California,

2) evaluating builder perspectives on value of and barriers to implementing ventilation standards,

3) developing and testing energy-efficient strategies and technologies for providing appropriate ventilation in California homes, and

4) providing technical support to the commission in developing code changes and in the associated implementation.

The fulfillment of the objectives can be evaluated by:

- surveying builders and contractors about incidences of ventilation-related IEQ and durability problems and the type of ventilation methods used to prevent these problems,
- analysis of these reported problems in terms of how ventilation could contribute to or reduce their occurrence and development of guidelines for builders and contractors,
- field and laboratory measurement of ventilation system energy consumption and evaluation of other performance issues such as durability, maintenance requirements, noise, etc.,
- production of a guideline for California builders and contractors on how to select and install energy efficient ventilation systems that meet the needs of California housing, and
- resulting draft standard language

KEY ISSUES

In scoping the R&D necessary to fulfill the above objectives regarding ventilation technologies for residential ventilation in California, we have identified key issues that require further consideration. In order for the goals and objectives of this project to be adequately achieved, these key issues must be addressed and resolved in the course of the project.

Compatibility with Title 24 and Other Ventilation Code Requirements

For ventilation technologies to be used by the building industry they must be compatible with codes and regulations. A good starting point is to look at existing ventilation standard requirements. Currently, Title 24, Chapter 4: Compliance through quality construction, states:

- If the Specific Leakage Area (SLA[1]) is less than 1.5, continuous mechanical supply ventilation is required. The cfm supplied must be sufficient to maintain the house at (or above) -5 Pa (relative to outside) when all exhaust fans are operating.
- If the SLA is less than 3.0, continuous mechanical ventilation is required (either exhaust or supply). The minimum capacity of the supplied ventilation is 0.047 cfm per square foot of conditioned area.
- Power consumption of the vent fans must be reported.

A summary of ventilation related code requirements for other states is given in the companion Requirements scoping study.

The proposed ASHRAE Standard 62.2 (ASHRAE 2003) for low rise residential buildings would require local ventilation rates on the order of 20 to 100 cfm. Less than 150 cfm of ventilation would be needed to satisfy whole-house continuous ventilation requirements for most homes and for intermittent operation, a fan with a capacity of less than 400 cfm, operating less than 35% of the time would satisfy 62.2 requirements.

These ventilation code requirements indicate the approximate values for key parameters, such as required air flow rates, and how they can change depending on building size and occupancy. For ventilation technologies to be acceptable they must be able to meet the intent of codes and standards; therefore it is important to understand code requirements. In addition, for ventilation technologies to be widely used they will need to meet a range of code requirements; therefore knowledge of these requirements is essential when evaluating different technologies.

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[1] "SLA" is currently used in Title 24, but "NL" (Normalized Leakage) is now used by ASHRAE. An evaluation of this distinction should be made as part of the overall project.

Improving Ventilation System Performance

For a ventilation technology to be acceptable it will need to address the shortcomings of existing systems and offer potential improvements. The following is a list for improving performance of existing ventilation systems. Some of these apply only to individual technologies and some are relevant for any ventilation technology.

- Reduce energy consumption by using passive ventilation systems, better fans, low flow-resistance ducting, and correct air flow rates.
- Reduce noise and unpleasant drafts (that make occupants turn ventilation systems off) to increase occupant comfort and acceptance.
- Increase durability to make systems that last for a long time (e.g. 20 years), and require little or no maintenance (also increasing occupant acceptance).
- Improve source control by adding fans and vents near sources (primarily kitchens and bathrooms),
- Better distribution of ventilation air throughout a house.
- Reduce intake of pollutants from areas that ducts pass through (garages, crawlspaces, attics, basements) and ensure ventilation air is properly distributed, by using airtight ducts.
- Reduce energy consumption and noise and ensure correct air flow rates by using low flow-resistance ducts.
- Reduce ventilation air contributions to heating or cooling loads by using well insulated ducts.
- Reduce indoor pollutant levels by diluting indoor sources and reducing entry of outdoor sources (e.g., entry of air from garages where toxic compounds are stored or from damp crawlspaces that bring moisture into the home),
- Ensure the use of energy-efficient ventilation systems and strategies by changing ventilation requirements in building codes and standards.
- Improve information from manufacturers that is available for consumers. Unless fans come labeled with their efficiency rating then it is not possible for consumers to select higher efficiency fans, and any specification in efficiency standards will be unusable. People selecting equipment (builders and contractors) are not those who bear the consequences (occupants).
- Find a way for code authorities to establish minimum efficiency requirements for blowers/motors used in those appliances without bypassing the NAECA process.

Reducing the Energy Requirements of Ventilation System Fans

A key issue for mechanical ventilation systems is the energy use of air-moving fans. If Title 24 is to recommend or require the use of mechanical ventilation systems it will have to address the energy these systems consume. Most energy consumed by ventilation systems (not including the energy used to condition the air) is for fans and air handlers used to move air between inside and outside the house and mix the air within the house (a little energy is also used by monitoring and control devices).

Current air handlers and ventilation fans have poor performance. Typical furnace fan efficiencies are on the order of 15% (CMHC 1992 & 1993, Phillips 1998), but poor cabinet and duct design can reduce the efficiencies further. For comparison, individual exhaust fans typical of those used in bathroom and kitchen vents are even worse, with efficiencies of about 2%. The spread from best to worst systems in these studies and in the HVI (Home Ventilating Institute) directory (HVI 2003) is on the order of ten to one – so much better systems are clearly feasible. Field studies by LBNL and others (e.g., Proctor and Parker 2000) have shown that existing fans in residential air handlers typically consume 500 W or more of electricity and supply about 2 cfm/W. If this air handler fan is used in a ventilation system, assuming a 35% duty cycle, this is an average consumption of 175W. Over a whole year this amounts to about 500 kWh. At $0.15 per kWh the cost is about $75/year. Recent testing of a prototype air handler with an ECM motor (Walker and Mingee 2003 and Walker et al. 2003) and improved design of the fan blade and housing showed a doubling of air handler efficiency. There is an opportunity here to push the industry towards the use of much more efficient air handler and ventilation fans by specifying minimum efficiencies in the building standards. The HVI directory (HVI 2003) specifies power consumption for a few fans, but not for most. The information exists, because it is part of the standard rating procedure – it just isn't published. If building codes specified minimum acceptable efficiencies, manufacturers and rating agencies would be encouraged to report these values.

Providing Simple Paths for Code Compliance

For builders and contactors to adopt a particular ventilation technology there must be an easy way to verify or certify code compliance. The ultimate goal of this project is to produce a residential ventilation code that is practical, acceptable by the building industry, cost-effective and protective of occupant health and safety. To do so requires that the results of this effort not only meet the technical objectives outlined above, but also are compatible with the requirements of many of the stakeholders in the area. Therefore an important consideration when examining potential technologies is the ease of verifying or certifying performance, allowing a simple path to code compliance. For example, building codes could specify ARI ratings of air flow and noise and then a simple building inspection would certify the use of products with ARI ratings that meet the code requirements.

How is Ventilation Technology Selection Impacted by Time Dependent Valuation (TDV)?

If energy costs are varied to account for the real time costs of generation, transmission and/or distribution, then the economics of different ventilation technologies will change. Such a weighting would mix the traditional concepts of energy and demand.

A recent change made to Title 24 places a time-dependent valuation (TDV) on energy use. The philosophy of TDV is to make energy demand more uniform by increasing the value and cost of energy consumed during peak-use periods. In this report we will discuss TDV-related issues under the heading of "demand".

The energy cost of ventilation is not constant: it depends not only on the ventilation rate, but also on the enthalpy difference between indoor and outdoor air. Ventilation energy cost can be quite high during the peak-demand weather conditions (heat of summer and cold of winter). But during mildly warm conditions when ventilation supplies free cooling, its cost is low and can even be negative.

Existing Residential Ventilation Technologies Potentially Applicable to California

In the following sections is a list of the existing ventilation technologies that could be used in California. The capabilities of each technology are evaluated using the following criteria: energy impacts, source control capabilities, demand impacts, costs, additional market barriers, durability and maintenance requirements, ease of inclusion in building design and construction, issues of meeting potential code requirements and impact on Title 24 algorithms. These criteria were selected to address the issues raised above as well as to provide a summary of the performance and requirements of each technology. The intent is to provide information to guide the future work in this area and to provide the basis for comparisons between different ventilation technologies.

The sections below focus on ventilation technologies for use in providing whole-building ventilation, but all houses also must have local exhaust ventilation to deal with contaminants in specific rooms—such as kitchens, bathrooms, laundry, etc. The most common technology is the intermittent (i.e. occupant controlled) exhaust fan. These local exhaust technologies, which parallel other exhaust technologies, will not be discussed in detail in this scoping study, but must be covered as part of the research project.

It should be noted that some local exhaust strategies can serve double duty as whole-building ventilation strategies. Such synergies can improve IAQ, reduce the first cost of ventilation equipment and reduce energy consumption. Any future research must account for such combinations and options.

Additional building code issues are covered by the companion study: Residential Ventilation Standards Scoping Study (McKone and Sherman 2003).

1. Continuous exhaust

A continuous exhaust system uses a fan (or fans) to exhaust air from the building, with air entering through leaks in the building envelope. Air may be exhausted from multiple locations using several individual fans. Alternatively, a single fan can be used together with a network of small ducts to extract air from multiple locations.

Energy impacts: Continuous exhaust requires energy to operate the fan, but most of the energy requirements are for conditioning the air brought into the house elsewhere. The HVI directory lists energy use for some fans and they show a wide range of performance from less than 1 cfm/W to about 4 cfm/W. This indicates that fan selection is critical in reducing ventilation related energy consumption. Energy use for continuously operating systems can be much higher than for intermittent systems.

Source control capabilities: If the exhaust is from areas of high source strength then indoor concentrations of pollutants can be well controlled. Typical examples are exhausting moisture from bathrooms, or cooking products from kitchens. There is no opportunity to filter the air entering the house. There is the possibility to install two-speed systems that can be operated at a higher speed for a limited time in case of high indoor pollutant concentrations (during parties, to remove cooking odors, or to remove paint fumes etc.). The entry point of the air into the building is not controlled using this ventilation method and it may come from undesirable locations such as dusty, humid attics or crawlspaces or attached garages containing multiple pollutants. Unless care is taken to reduce these potential sources in the incoming air exhaust, ventilation may *increase* indoor levels of pollutants.

Demand impacts: There is no ability to shift operation off-peak (or have reduced on-peak operation). The energy impact is greatest for these systems under peak heating and cooling load situations.

Heat recovery potential: There is the possibility for passive heat recovery for the air flowing in through the building leaks. However, as has been discussed by Sherman and Walker (2003), for normal leaks typical of building envelopes (i.e., not specifically designed to maximize IHR) the heat recovery will only reduce the infiltration-related load by about 10%.

Costs: First cost can be low due to the simplicity of the equipment (no timers or sensors are required) and ease of installation. The addition of a multi-port duct system will add substantial material and installation costs for the ducting. Operating costs are high due to the electricity used to run the fan and the conditioning of air entering the house.

Additional market barriers or assets: It is preferable to have as little noise as possible from these systems (although a truly silent system may require a simple activity/trouble light to indicate a need for servicing or repair). This technology uses common equipment and is easy to install in houses, so the barriers to use and acceptance by the building industry are low. While exhaust fans are installed in almost all new construction and renovations, they are often low-efficiency devices (typically around 2%) and the higher efficiency fans that would be appropriate for a continuous ventilation application are comparatively rare. Therefore some market changes are required to ensure the use of high efficiency fans only. Occupants are used to having exhaust fans in kitchens and bathrooms, so aesthetically and functionally they should be readily accepted by the occupants.

Durability and maintenance requirements: If there is no filtration on the fan entry then the fan and ductwork will become dirty and dusty with time. This will eventually restrict the air flow such that it no longer meets the minimum air flow requirements. The time it takes to reach this point is highly variable depending on the sources of dust and other airborne particles in the house. Most fans on the market are designed to require no periodic maintenance and will simply fail after a number of years. The source of failure is typically that the bearings wear out and the fan at first becomes noisy and eventually the fan stops turning altogether.

Ease of inclusion in building design and construction: Ducting to outside (usually up to the roof) is required, but at the typically low flow rates required of these systems only small ducts (< 4 inch (100 mm diameter)) are required. This allows the ducts to be run inside interior partitions with minimum effort. Alternatively, they could be installed in through-wall applications eliminating the need for ducting.

Issues of meeting potential building code requirements: The fan inlets and outlets should be visible upon completion of a home. The ducting between air inlets and fans needs to be inspected during construction before being enclosed in building cavities. It should be relatively simple to assess the size and condition of ducting at some point during construction. To meet possible flow, efficiency and sound requirements, some sort of rating (e.g. ARI) could easily be verified. One issue that may require field testing is that ducts with high flow resistance can reduce the flow through the system below the minimum requirements. It is not clear how continuous use should be penalized in terms of energy use if it is only providing the minimum requirements. If the code values time of operation (to avoid peak demand and costs) then there may be a penalty associated with continuous operation. It is important to avoid excessive building depressurization when using exhaust fans. This is particularly important for houses with natural draft combustion appliances that are either inside or are well connected (by air flow paths) to the inside because excessive depressurization can lead to spillage of combustion products. Typical sources of combustion products are water heaters, which have generally unpredictable operating times. T24 already has some depressurization restrictions based on envelope leakage: tight envelopes (SLA<1.5) require a supplementary supply fan to prevent depressurization below –5Pa when all exhaust fans are operating.

Impact on T24 algorithms: Need to include additional mechanical ventilation in load estimates.

2. Intermittent exhaust.

An intermittent exhaust system uses a fan to exhaust air from the building, with air entering through leaks in the building envelope. The fan is controlled by a timer and may also have occupant overrides to turn on the ventilation system during periods of high pollutant generation. Air may be exhausted from multiple locations using several individual fans. Alternatively, a single fan can be used together with a network of small ducts to extract air from multiple locations.

Energy impacts: Intermittent exhaust requires energy to operate the fan, but most of the energy requirements are for conditioning the air brought into the house elsewhere. The use of a control system to turn the fan on and off could operate simply on a timer, or it may include other control parameters such as air temperatures or humidity. In addition intermittent exhaust may be used to remove pollutants at specific times or to add ventilation when natural driving forces are low (little/no wind and mild outdoor temperatures). The reduced time of operation and the ability to operate when outdoor air is close to indoor air temperature (if an appropriate control system is used) together potentially reduce the energy used to condition outside air entering the house.

Source control capabilities: If the exhaust is from areas of high source strength, then indoor concentrations of pollutants can be well controlled. Intermittent fans are more useful for sources that occur periodically, such as cooking or bathing, rather than sources that emit more constantly, such as building materials. There is no opportunity to filter the air entering the house. The common kitchen and bathroom exhaust fans in many existing houses are used to control these intermittent sources (whether required by code or not). Some source control activities may be automated. For example using a humidity controller in a bathroom to turn the fan on at a fixed humidity level, or using a timer to turn on ventilation at fixed times of day. The entry point of the air into the building is not controlled using this ventilation method and it may come from undesirable locations such as dusty, humid attics or crawlspaces or attached garages containing multiple pollutants. Unless care is taken to reduce these potential sources in the incoming air, exhaust only ventilation may *increase* indoor levels of pollutants.

Demand impacts: There is the possibility to shift operation off-peak user timer controls. There will often be a balance between needing to remove sources at specific times and the desire to avoid peak operation. For example, summertime indoor evening meal preparation coincides with the summer peak load for air conditioning. If the cooking pollutants are to be removed, then this would require peak time operation.

Heat recovery potential: There is the possibility for passive heat recovery for the air flowing in through building leaks. However, as has been discussed by Sherman and Walker (2003), the normal leaks typical of building envelopes (i.e., not specifically designed to maximize IHR) the heat recovery will only reduce the infiltration-related load by about 10%. This is likely to be further reduced by the cyclic nature of intermittent operation, as the building envelop components through which the air flows will need to heat up or cool down at the beginning of each cycle.

Costs: First cost can be low due to the simplicity of the equipment and because these installations are common in existing construction. Operating costs are highly variable depending on how much time the fan operates. These costs can be reduced by ensuring that the fans are correctly sized (i.e., do not have excessive air flow rates) and that the fans operate efficiently. This efficient operation can be determined by the ratings for the fans (if available) and by ensuring good installation. Good installation includes minimizing any duct runs and air flow resistance (e.g., avoiding excessive bends). Adding controls (usually timers or humidistats) adds a small amount of cost but this may balanced by reducing the use of the fans when not required for source control.

Additional market barriers or assets: Because similar systems are already installed in houses they have the advantage of familiarity. Exhaust fans are installed in almost all new construction and renovations but they are often low efficiency devices (typically around 2%). The higher efficiency fans that would be appropriate for a continuous ventilation application are comparatively rare. Therefore some market changes are required that would lead to the use of only high efficiency fans. Occupants are used to having exhaust fans in kitchens and bathrooms, so aesthetically and functionally they should be readily accepted by the occupants.

Durability and maintenance requirements: If there is no filtration on the fan entry then the fan and ductwork will become dirty and dusty with time. This will eventually restrict the air flow such that it no longer meets the minimum air flow requirements. The time it takes to reach this point is highly variable depending on the sources of dust and other airborne particles in the house, and how often the system is used. Most fans on the market are designed to require no periodic maintenance and will simply fail after a number of years. The source of failure is typically that the bearings wear out, so that the fan first becomes noisy and eventually stops turning altogether.

Ease of inclusion in building design and construction: Ducting to outside (usually up to the roof) is required, but at the typically low flow rates required of these systems only small ducts (< 4 inch (100 mm diameter)) are required. This allows the ducts to be run inside interior partitions with minimum effort. Alternatively, they could be installed in through-wall applications eliminating the need for ducting.

Issues of meeting potential building code requirements: The fan inlets and outlets should be visible upon completion of a home. The ducting between air inlets and fans needs to be inspected during construction before being enclosed in building cavities. It should be relatively simple to assess the size and condition of ducting at some point during construction. To meet possible flow, efficiency and sound requirements some sort of rating (e.g. ARI) could easily be verified. One issue that may require field testing is that ducts with high flow-resistance can reduce the flow through the system below the minimum requirements. If the code values time of operation (to avoid peak demand and costs) then there may be advantages associated with intermittent operation. It is important to avoid excessive building depressurization when using exhaust fans. This is particularly important for houses with natural draft combustion appliances that are either inside or are well connected (by air flow paths) to the inside because excessive depressurization can lead to spillage of combustion products. Typical such sources of combustion products are water heaters, which have generally unpredictable operating times. There are several sources of information (e.g. ASTM guidelines) regarding depressurization limits and diagnostics for estimating depressurization and predicting the performance of flues that could become recommended code practice.

Impact on T24 algorithms: If T24 algorithms are to include time of use issues, then some standard operating pattern for intermittent operation will be required to compare designs. This will be further complicated by additional controls using time or humidity to control fans.

3. Exhaust with makeup air: inlet louvers (trickle vents)

This technology builds on the previous two exhaust fan technologies. It is a method of controlling the point of entry of outdoor air into the building. For example, putting inlet louvers under windows in bedrooms is a common application that ensures that outdoor air is preferentially supplied to these rooms. An exhaust system like those previously described is used to ensure air movement. The inlet louvers provide deliberate openings in the building envelope for air entry. They are often integrated into window frames to simplify the construction process.

Energy impacts: Adding deliberate makeup air entry points to the building envelope in conjunction with exhaust only systems should not change the energy use of these system during operation. For intermittent operation, the makeup air vents add to the envelope leakage and will increase the natural ventilation air flows compared to the same house envelope without the vents. However, trickle vents are usually only used in conjunction with relatively tight envelopes – so the additional natural ventilation from the trickle vents needs to be balanced against the lower natural ventilation rates associated with these tighter envelopes.

Source control capabilities: The main sources in bathrooms and kitchens can be exhausted directly by placing the exhaust fans in those rooms or ducting a single fan to these locations. There is no direct source control using these passive devices; for entry of outside air however, in conjunction with a tight building envelope they can control the entry point for outdoor air. For this reason they are commonly found in bedrooms so that outdoor air is supplied to these rooms specifically. The entry point of the air into the building is better controlled using the trickle vents and so it reduces the problems associated with air coming from undesirable locations such as dusty, humid attics or crawlspaces or attached garages containing multiple pollutants.

Demand impacts: The demand impacts will depend on the mechanical ventilation system they are used with.

Heat recovery potential: Air flowing through the louvers will bypass the rest of the building envelope and the already small potential for infiltration heat recovery will be further reduced.

Costs: There are moderate material costs for the inlets as well as installation costs. These costs can be highly variable; however, in other countries there are mature markets for these devices that could be used as pricing models. Installation costs are significantly reduced by integrating the vents into window frames, thus simplifying the installation procedure.

Additional market barriers or assets: These systems are relatively rare in the US, but are more common in other countries. There may remain some market issues to be resolved in the US before they achieve common acceptability. For example, how can these systems deal effectively with the possibility of cold drafts in wintertime (although well-designed vents reduce this problem). Because these vents may be adjusted by the occupants, they may have a market advantage for people who want to control the systems themselves.

Durability and maintenance requirements: The maintenance requirements are very low, other than periodic cleaning to remove dust and dirt build-up. If there is no filtration in the air entry then the vents will become dirty and dusty with time. This will eventually restrict the air flow such that it no longer meets the minimum air flow requirements. The time it takes to reach this point is highly variable depending on the sources of dust and other airborne particles in outdoor air (and in the house) and how often the mechanical exhaust system is used. There is nothing mechanical to fail other than the passages becoming blocked and restricting flow.

Ease of inclusion in building design and construction: These vents are generally small and unobtrusive and are usually mounted where there is some other change in the building envelope (such as a window). This makes them easy to include in the design and construction.

Issues of meeting potential building code requirements: These vents can be used to reduce concerns about building depressurization from exhaust fans and the effect on combustion appliances and so may be required in codes as part of a complete system in conjunction with an exhaust fan.

Impact on T24 algorithms: The additional envelope leakage may contribute to natural ventilation with the exhaust fans off and require changes to ventilation loads.

4. Intermittent or continuous local exhaust with makeup air from inlet in return

This method of providing ventilation builds on the first two exhaust systems described above (constant and intermittent). The air inlet in the return of the system draws air into the duct system that is then distributed throughout the house using the same supply ducts and air handler that are used to distribute conditioned air. The idea is to provide distribution throughout the house without having to install a ventilation-specific supply duct system. The return inlet also provides ventilation air whenever the heating or cooling system is operating.

Energy impacts: Adding a deliberate makeup air entry point to the HVAC duct system in conjunction with an exhaust fan should not change the energy use of these systems during operation. For intermittent fan operation, the inlet in the return will add to the envelope leakage and will increase the natural ventilation air flows compared to the same house envelope without the vents. However, a simple damper system could be used to close the return inlet when the exhaust or mechanical ventilation fan is not operating. Additional energy impacts may arise if the ventilation air passes through ducts in unconditioned spaces. The low levels of duct insulation typically found in houses mean that the ventilation air may be heated or cooled as it passes through ducts in attics, crawlspaces or garages. If the air is heated above ambient (or cooled below ambient) conditions as it passes through these ducts then the energy impact of the ventilation air will be further increased.

Source control capabilities: The main sources in bathrooms and kitchens are exhausted directly by placing the exhaust fans in those rooms or ducting a single fan to these locations. The entry point of the air into the building is better controlled using the return inlet and reduces the problems associated with air coming from undesirable locations such as dusty, humid attics or crawlspaces or attached garage containing multiple pollutants. The outdoor air will tend to be distributed throughout the house (via the supply ducts) using this method for introducing outdoor air. This distributed supply will minimize potential problems such as cold drafts but it means that rooms with high source loads (kitchens, bathrooms and bedrooms at night) will not necessarily get outdoor air directly. Unlike the trickle vents it is more difficult for occupants to adjust the air flows for individual rooms because this would also change air flows during HVAC system operation.

Demand impacts: The demand impacts will depend on the mechanical ventilation system they are used with.

Heat recovery potential: Air flowing through the inlet will bypass the rest of the building envelope and the already small potential for infiltration heat recovery will be further reduced.

Costs: The costs are minimal for the return inlet – just a small duct and possibly a damper is required and the components and installation techniques are no different than current practice. However, there are additional controls required to determine how often the air handler fan should be turned on – depending on how often the heating or cooling is operating. This adds to the initial capital cost of the system. Also – using the air handler fan can use large amounts of energy unless an energy-efficient air handler in used. In particular, if the ventilation air handler flow is operated at a lower air flow rate than during heating or cooling operation, then an ECM motor is required because standard motors become very inefficient at low air flows.

Additional market barriers or assets: There are no significant market barriers; however, the industry needs to change from typical air handler fans to more efficient ones. In addition, there are commercially available systems to control the air handler depending on how often the heating or cooling operates.

Durability and maintenance requirements: The maintenance requirements are very low, other than periodic cleaning to remove dust and dirt build-up. There is a definite potential for adding filtration to the incoming air. Adding filtration has the benefit of providing cleaner outdoor air, but it will require the additional maintenance of periodic filter examination and replacement. For a simple inlet there is nothing mechanical to fail other than the passages becoming blocked and restricting flow. For damper-controlled inlets, the damper control will fail with time. The time to failure will depend on the quality of the electronic and electro-mechanical components. In this regard, anecdotal evidence indicates that current HVAC practice is to use extremely inexpensive components that lead to early failure.

Ease of inclusion in building design and construction: These vents are generally small and unobtrusive and are usually mounted where they are easy to install. Additional design effort may be required if filters are included to allow for easy filter access.

Issues of meeting potential building code requirements: These vents can be used to reduce concerns about building depressurization from exhaust fans and the effect on combustion appliances and so may be required in codes as part of a complete system in conjunction with an exhaust fan.

Impact on T24 algorithms: Without dampers, the contribution of these vents to envelope leakage may contribute to natural ventilation with the exhaust fans off and require changes to ventilation loads.

5. Continuous supply

A continuous supply fan supplies air to the house rather than exhausting it. A continuous supply would benefit from using a ducted distribution system to spread outdoor air throughout the house. This distribution could be fairly simple, using small diameter ducts that would fit in wall and floor cavities distributing air to only three or four locations. Alternatively, several individual supply fans could be installed in different parts of the house without a duct distribution system. To control the level of house pressurization a pressure relief valve may be used that opens at a fixed pressure.

Energy impacts: Continuous supply requires energy to operate the fan, but most of the energy requirements are for conditioning the air brought into the house through the fan.

Source control capabilities: Supply air flows do not directly exhaust polluted air to outside and so can only control the sources by dilution – which is much less preferable. Some sort of air tempering will be required to prevent cold drafts in some climates. The entry point of the air into the building is better controlled using a dedicated supply fan and so it reduces the problems associated with air coming from undesirable locations such as dusty, humid attics or crawlspaces or attached garage that contain multiple pollutants. It is possible to filter the incoming air so as to control outdoor air pollutants.

Demand impacts: With continuous operation there is no ability to shift operation off-peak (or have reduced on-peak operation). Under peak heating and cooling load situations is when the energy impact is greatest for these systems.

Heat recovery potential: The only heat recovery potential using supply fans is the infiltration heat recovery in the air exiting through the building envelope.

Costs: First cost can be low due to the simplicity of the equipment (no timers or sensors are required) and ease of installation. Operating costs are high due to electricity used to run the fan and conditioning of air entering the house.

Additional market barriers or assets: It is preferable that these systems make as little noise as possible (although a truly silent system may require a simple activity/trouble light to indicate a need for servicing or repair). Supply fans are much less common than exhaust fans and therefore have potentially high barriers to use and acceptance by the building industry. The ability to filter incoming air may act to reduce market barriers because this may be desired by building occupants.

Durability and maintenance requirements: If there is no filtration on the fan entry then the fan and ductwork will become dirty and dusty with time. This will eventually restrict the air flow such that it no longer meets the minimum air flow requirements. The time it takes to reach this point is highly variable depending on the sources of dust and other airborne particles in the house. With a supply fan it is possible to filter the air entering the fan and therefore reduce the problems due to dirt accumulation. Filtration reduces this dirt accumulation problem, but adds the requirement to periodically inspect and clear filters. Most fans on the market are designed to require no periodic maintenance and will simply fail after a number of years. The source of failure is typically that the bearings wear out, so that the fan first becomes noisy and eventually stops turning altogether. If a pressure relief valve is used it may require periodic maintenance and is an additional component that may fail over time. Anecdotal evidence indicates that current HVAC practice is to use extremely inexpensive components for pressure relief that lead to early failure. Therefore future applications will require improved components.

Ease of inclusion in building design and construction: Ducting to outside is necessary, but at the typically low flow rates required of these systems only small ducts (< 4 inch (100 mm diameter)) are required. This allows the ducts to be run inside interior partitions with minimum effort. Alternatively, they could be installed in through-wall applications eliminating the need for ducting.

Issues of meeting potential building code requirements: The fan inlets and outlets should be visible upon completion of a home. The ducting between air inlets and fans needs to be inspected during construction before being enclosed in building cavities. It should be relatively simple to assess the size and condition of ducting at some point during construction. To meet possible flow, efficiency and sound requirements, some sort of rating (e.g. ARI) could easily be verified. One issue that may require field testing is that ducts with high flow-resistance can reduce the flow through the system below the minimum requirements. It is not clear how continuous use should be penalized in terms of energy use if it is only providing the minimum requirements. If the code values time of operation (to avoid peak demand and costs) then there may be a penalty associated with continuous operation.

Impact on T24 algorithms: Need to include additional mechanical ventilation in load estimates.

6. Intermittent supply with inlet in return of HVAC system

An inlet placed in the return of the HVAC system allows outdoor air entry when the air handler fan operates. This effectively acts as a supply fan that provides air in a distributed manner through the existing supply ducting. When the HVAC system is not operating this hole may be open or closed. If it is left open then it adds to envelope leakage of the building. If it is closed, then the ventilation when the air handler is off is not changed by the addition of this hole. This ventilation method will tend to pressurize the house and in some cases a pressure relief vent is used. The pressure relief vent is usually placed in the supply ducting or plenum and allows the house pressure to be controlled.

Energy impacts: In general, air handler fans are more efficient than most simple exhaust or supply fans. Therefore, for the same amount of air movement during a day, less fan energy will be used. However, the short-term peak demand may be larger because the air handler fan draws more power during operation. The inlet acts as a return duct leak during heating and cooling operation that can have significant energy penalties because the air is drawn from unconditioned spaces. When the heating or cooling is not operating, the inlet in the return will add to the envelope leakage (unless a damper is used to close the vent) and will increase the natural ventilation air flows and associated space conditioning energy. There are two possible modes of operation for this system: only operating when the HVAC system is calling for heating or cooling, or operating on a timer so that the air handler is periodically turned on even when there is no heating or cooling (this type of cycling system is already commercially available and is used in Building America homes). In the first mode there is probably little fan energy penalty, as the fan would have been operating anyway and the total air flow rates would be about the same. However, this mode of operation would require a secondary ventilation system for use in shoulder systems when heating or cooling is rare and it is therefore more likely that the second mode would be used.

Source control capabilities: There is no direct source control using this device. However, in conjunction with a tight building envelope the entry point for outdoor air can be controlled. The outdoor air will tend to be distributed throughout the house (via the supply ducts) using this method for introducing outdoor air. This distributed supply will minimize potential problems such as cold drafts, but it means that rooms with high source loads (kitchens, bathrooms, and bedrooms at night) will not necessarily get outdoor air directly. It is difficult for occupants to adjust the air flows for individual rooms because this would also change air flows during HVAC system operation. It is possible to add filtration to the inlet so as to remove some outdoor air pollutants before they enter the building.

Demand impacts: Because the intermittent operation of this system is linked to HVAC system operation it tends to increase ventilation at the worst time – peak conditions. If the system is operated on a timer when no heating or cooling is occurring this could contribute further to utility peak demand.

Heat recovery potential: The only heat recovery using a simple inlet in the return is from the infiltration heat recovery from air exiting through the building envelope.

Costs: The costs are minimal for the return inlet – just a small duct and possibly a damper is required and the components and installation techniques are no different than current practice.

Additional market barriers or assets: There are no significant market barriers. An asset is that the supply air is conditioned rather than at outdoor temperature and humidity.

Durability and maintenance requirements: The maintenance requirements are very low, other than periodic cleaning to remove dust and dirt build-up. There is a definite potential for adding filtration to the incoming air. Adding filtration has the benefit of providing cleaner outdoor air, but it will require the additional maintenance of periodic filter examination and replacement. For a simple inlet there is nothing mechanical to fail other than the passages becoming blocked and restricting flow. For damper controlled inlets, the damper control will fail with time. The time to failure will depend on the quality of the electronic and electro-mechanical components. In this regard, anecdotal evidence indicates that current HVAC practice is to use extremely inexpensive components that lead to early failure. Therefore future applications will require improved components (as for exhaust fans). If a pressure relief valve is used, it may require periodic maintenance and is an additional component that may fail over time.

Ease of inclusion in building design and construction: These vents are generally small and unobtrusive and are usually mounted where they are easy to install. Additional design effort may be required if filters are included to allow for easy filter access.

Issues of meeting potential building code requirements: The fan inlets and outlets should be visible upon completion of a home. The ducting between air inlets and fans needs to be inspected during construction before being enclosed in building cavities. It should be relatively simple to assess the size and condition of ducting at some point during construction.

Impact on T24 algorithms: Vents that go directly into the HVAC system may be included in T24 algorithms related to both the envelope loads and equipment/duct system. Without dampers, the contribution of these vents to envelope leakage may contribute to natural ventilation with the exhaust fans off and require changes to ventilation loads.

7. Combined exhaust and supply

The combination of exhaust fan(s) and supply fan(s) provide balanced ventilation with little building pressurization or depressurization. A common method of combining exhaust and supply fans is in a Heat Recovery Ventilator (HRV).

Energy impacts: Adding deliberate makeup supply fans in conjunction with exhaust only systems will increase the electrical energy consumption of the system during operation compared to having only an exhaust fan. However, the ability to target specific locations with the supply, withthe possibility to reduce total air flows or reduce intermittent operation, can reduce this energy impact. HRV's require energy to operate the fan. As with simple exhaust and supply fans there is a range of performance, but typical systems supply about 1.5 cfm/W (based on data in the HVI directory (HVI 2003)). Typical sensible efficiencies are from 60% to 70%, resulting in significant reductions in the energy required to condition the ventilation air. HRVs have a wide range of performance for dealing with humidity in cooling applications, with cooling efficiencies ranging from less than 10% to greater then 40%. In most California climates this will not be an important issue due to the dominance of sensible loads. Lastly, many California climates experience relatively mild weather conditions and so avoid some of the HRV energy-use problems related to operating in extremely cold climates (e.g., defrost cycles and cold drafts).

Source control capabilities: The main sources in bathrooms and kitchens are exhausted directly by placing the exhaust fans, or ducting to a single fan, in those rooms. The entry point of the air into the building is better controlled using a dedicated supply fan, which reduces the problems associated with air coming from undesirable locations such as dusty, humid attics or crawlspaces or attached garages containing multiple pollutants. The supply fans for either stand-alone or HRV applications provide the opportunity to filter outdoor air before it enters the building.

Demand impacts: With continuous operation there is no ability to shift operation off-peak (or have reduced on-peak operation). Peak heating and cooling load situations are when the energy impact is greatest for these systems; however, the use on an HRV can significantly reduce the peak demand effects compared to other ventilation systems with no heat recovery.

Heat recovery potential: For simple supply and exhaust fans there is almost no heat recovery potential. In contrast, HRVs are specifically designed to maximize heat recovery from ventilation air.

Costs: The installation costs for a simple supply fan are about the same as for an exhaust fan. For HRVs, first costs are higher for both materials and labor because HRVs require a good installation to function properly (problems related to poor installation have historically dogged HRV use); however, HRVs offer considerable savings on the energy required to condition ventilation air. Operating costs for combined supply and exhaust systems will be higher than for systems with supply or return alone because extra fans need to be operated. For HRVs there is a balance of the electricity used to run the fan and the reduced requirement for conditioning of air entering the house.

Additional market barriers or assets: The market barriers for supply fans are similar to those for exhaust fans and include issues of noise and aesthetic acceptability. The major barrier to adopting HRVs is the high first cost. HRVs are a well-developed technology and are common in some parts of the country. It is preferable for these systems to produce as little noise as possible (although a truly silent system may require a simple activity/trouble light to indicate a need for servicing or repair). The ability to filter incoming air, which may be desired by building occupants, may act to reduce market barriers,.

Durability and maintenance requirements: If there is no filtration on the supply fan entry then the fan, ductwork and heat exchanger will become dirty and dusty with time. This will eventually restrict the air flow such that it no longer meets the minimum air flow requirements, and for HRVs it will reduce the effectiveness of the heat exchanger. The time it takes to reach this point is highly variable depending on the sources of dust and other airborne particles in the house. Filtration reduces this dirt accumulation problem, but adds the requirement to periodically inspect and clear filters. To maintain HRV performance it is essential to have regular cleaning/servicing.

Ease of inclusion in building design and construction: This issue is slightly more problematic than for exhaust fans alone because of occupant sensitivity to supply air (particularly if it is unconditioned). Therefore careful thought is required regarding placement. In addition, in order to prevent short circuiting, the supply fans need to be strategically placed in the building to create flows through the interior volume. For dedicated HRV systems, the air can be supplied much closer to indoor conditions and it would therefore be easier to integrate into the building design. On the other hand, HRVs tend to be physically bulky and require mounting in a location within the building structure that allows access for maintenance and easy connection to electrical power and forced air ducting. There are many building designers in other states who already have experience with HRVs, so there is the possibility for California builders and designers to learn from other states where HRV use is more common about good installation practices.

Issues of meeting potential building code requirements: Balanced supply and exhaust fans can be used to reduce concerns about building depressurization from exhaust fans and the effect on combustion appliances, and so may be required in codes as part of a complete system in conjunction with an exhaust fan. Currently, T24 requires supply fans to be installed in houses that are tighter than SLA=1.5 to prevent depressurization greater than –5Pa with all exhaust fans operating. To meet possible flow, efficiency and sound requirements, some sort of rating (e.g. from HVI) could easily be specified and verified. One issue that may require field testing is that ducts with high flow-resistance can reduce the flow through the system below the minimum requirements.

Impact on T24 algorithms: The extra fan energy and ventilation air supply need to be accounted for in the T24 building load and energy use calculations. For HRVs a method of accounting for the reduction in ventilation-induced building load must be included. Some sort of HRV model calculation would be required that included inputs of air flow, efficiencies (both sensible and total) and fan energy use.

8. Operable windows

Operable windows rely on the occupants of the building to open and close windows to control the ventilation rate. Locations that commonly have high indoor pollutant concentrations (kitchens, bathrooms and bedrooms) will almost always have an operable window. Because the flow through an open window depends on ambient weather conditions it is highly variable – resulting in overventilation and underventilation. In addition, occupants are not very good pollutant sensors. This makes windows an unreliable method of ventilation and indoor air pollutant control.

Energy impacts: As no energy is required to operate this system, energy is required only for conditioning the air brought into the house. With operable windows a major energy concern is the uncontrolled ventilation that can be much greater than the amount required for good indoor air quality. This can result in considerable excess energy use.

Source control capabilities: If windows are opened in rooms that are the source of pollution then the source can be controlled if the air flow is out through the window. Unfortunately the direction of air flow is difficult to guarantee and so windows are not a reliable source control device. In addition, many parts of California have high outdoor particle concentrations and windows would allow entry of large quantities of particles.

Demand impacts: With both window operation and air flow through windows being highly variable it is difficult to determine peak demand effects. Because indoor to outdoor temperature differences tend to be greatest at peak demand times this means that times of maximum flows through windows coincide with times of greatest indoor to outdoor enthalpy difference. This means that open windows will have a big peak demand effect. The counter argument to this is that people will tend to keep windows closed if it is particularly hot or cold outside; however, this limits the utility of operable windows as air quality control devices.

Heat recovery potential: There is no heat recovery potential from open windows.

Costs: There is no change in construction cost because houses have operable windows already.

Additional market barriers or assets: Some issues with windows used as providers of outdoor air are: security – some occupants will not want to leave windows open because of security issues; noise – the desire to reduce disturbing noise from outside (e.g., traffic) will prevent some occupants from opening windows; and weather – during bad weather (e.g., rain, snow or high winds) occupants will not want to open windows to prevent moisture entry or the disturbance caused by strong drafts. These are all barriers to the use of windows as reliable ventilation providers. Conversely, windows have the benefit of familiarity. However, systematically optimizing window use (e.g., closing windows when outdoor temperatures are too high or too low, or using cool night air to pre-cool a building) is beyond the capabilities of most occupants. Lastly, windows are not always easy to open or close and the effort required may be beyond some occupants – e.g., the aged or infirm.

Durability and maintenance requirements: Little maintenance is required other than the periodic cleaning of duct and dirt from insect screens (if present). In terms of long-term durability there can be some concerns, such as the painting shut of otherwise operable windows. This is more of an issue in older construction (and in regularly painted rental accommodation). In newer construction that uses (often unpaintable) vinyl window frames this concern is reduced.

Ease of inclusion in building design and construction: Standard building designs already include windows so no extra effort is required.

Issues of meeting potential building code requirements: The key issue is reliability of service. Although open windows are a simple approach they cannot be used to provide the service of good indoor air quality because the occupants are free to open or close windows as they wish. Operable windows are not suitable for satisfying ventilation requirements in a building code because the code cannot enforce occupant behavior.

Impact on T24 algorithms: Need to add the air flow through windows to the ventilation load. Some sort of standard window opening schedule would be required in order to compare designs.

Emerging Residential Ventilation Technologies Appropriate for California

In order to provide the best ventilation systems for California housing it is possible that new or emerging technologies may be more suitable and have better performance than existing technologies. The following list summarizes relatively recent technological advances and ideas that may be useful for California houses and offer significant benefits over existing systems. Given the conservative nature of the building industry, these systems need to be well understood before they are adopted. Their pros and cons must be articulated so that consumers, builders and contractors can make informed decisions and to assess their potential for inclusion in standards.

Passive systems: Passive systems that do not use fans to move air are increasingly common in Europe. These systems use trickle vents (usually window louvered inlets) and ventilation stacks or combinations of both. The ventilation stacks are usually located so as to draw air from kitchens and bathrooms (where sources such as moisture are strongest) up vertical shafts to the roof of the building. They rely on natural ventilation forces of wind and indoor-outdoor temperature difference. To minimize air flow rate variability, the location of the stack exit on the roof and the design of the vent cap are configured to reduce changes with wind direction (and somewhat with wind speed). The combination of consistent winds and relatively mild climate in some California climates appear ideal for these passive systems. They do need to be integrated into the building design because larger ducts are often required than for forced air systems (in an effort to reduce flow resistance). With larger diameter ducts the problems of dust and dirt accumulation are reduced. Because there is no fan these systems are essentially silent in operation. The only drawback is that even with very careful design and installation there will almost always be some time during the year when they do not provide sufficient air flow. Due to the limited pressures driving the airflow it would be difficult to provide any air filtration using these passive systems.

Hybrid systems: Hybrid systems are similar to passive systems, but they include small, low-power (as low as 2 W) fans to boost the air flows through the passive vents. Although they give up the inherent simplicity of a passive system because electric supply is now required, they have the advantage of increased reliability. In times of low passive ventilation forces (low wind and small indoor-outdoor temperature differences) the booster fans allow the system to provide an acceptable minimum level of ventilation.

Economizers: The potential to provide significant cooling using economizers is highly variable with climate. Hot climates (CZ 15) allow almost no benefit – but CZ 12 and cooler climates allow about a 10% to 20% energy reduction – with greater savings in cooler climates (based on previous LBNL simulation studies). Cool climates allow dispensing with air-conditioners all together – a big cost saving (and peak power saver – because these cool climates only use air-conditioning on peak days). Economizers are already part of some energy-efficient packages offered by builders in California, but their use is limited by relatively high first cost. Economizers offer the ability to shift electricity use (for the air handler fan) off peak in the summer to the early hours of the morning and the possibility to filter the incoming air (although this would add to system maintenance requirements).

Discussing use of an economizer as a cooling technology is beyond the scope of this study, but they do provide ventilation in excess of what is needed for acceptable indoor air quality, which allows intermittent ventilation and passive strategies to be considered.

Air cleaning and filtration: An air cleaning and filtration system could be used to remove pollutants rather than to dilute them with outside air. This would have the advantages of not bringing outdoor pollutants into the home when outdoor air quality is poor, and issues of house pressurization or depressurization are avoided. However, this type of system would most likely require continuous operation using the forced air distribution system, in which case the performance of the distribution system (ducts and air handler) would be important. Ducts with little leakage, preferably inside the conditioned space, together with more efficient air handlers, would be required.

Depending on how future standards are changed, air cleaning and filtration could be mandatory (or could be an adjunct that allows a reduction of local exhaust or whole-building rates. An example of the former would be a requirement for particle filtration (e.g. MERV 6) upstream of any air handling equipment or components. An example of the latter might be activated carbon filtration to reduce contaminants of concern such as formaldehyde. It is, therefore, important to track the state of the art on these technologies and the development of future requirements.

RESEARCH PLAN

In order to address the key issues identified above and to achieve the corresponding goals and objectives in a timely manner, we must initiate a robust program of research relatively quickly. In this section we lay out a plan of research that addresses the issues, goals, and objectives described above.

This section provides a prototype research plan that does not have the level of detail normally expected in a proposal or contract document. We provide our best estimate of what is needed but we do not consider this directly suitable as a formal proposal or a contract document. It should serve, however, as a constructive basis for the formulation of whatever contract mechanism the Commission may wish to pursue.

In the process of defining research activities, we have identified various activities as being of high, medium or low priority. We believe all of these projects can help meet the objectives of the State and are worth doing. We believe those ranked high are critical to the success of the overall program. Those ranked medium should be done and have the potential to greatly improve the outcome of the project, but we believe the overall project might still be successful without them. Low priority projects are valuable and worth investing in, but are of sufficiently high risk, high cost, or long duration that they should be the first ones considered for elimination if there is a budget constraint.

The budgets for various activities are approximate budgets for the minimum amount of effort needed to achieve the research objectives. Except where explicitly noted the budgets do not include administrative burdens or contract overheads that might be required to convert these activities into a stand-alone program.

Deliverable dates are based on an assumed start date of December 1, 2003 and should be adjusted depending on actual start dates and timelines. We assumed that all critical path deliverables will be completed by June 30, 2005 to allow the Commission time to implement them in the 2008 standards. The program of work continues for an additional year to allow time for technical reports to be finalized, to provide support for the researchers to assist the CEC in preparing for hearings or other standards-implementation activities, and to complete any technology transfer activities.

Task 0: Administration

The individual tasks described below will achieve the goals and objectives outlined above, but the Commission may wish to have various administrative and coordination tasks accomplished in a manner similar to its programmatic contracts.

The Administration task provides the support needed to coordinate activities, manage the Project Advisory Committee, organize project reviews, prepare quarterly reports, create and maintain a project website, and prepare a project final report. This task also provides a person to interact with the Commission and its contract manager on administrative issues.

Priority: [required]
Quarterly Reports & website updates: March 2004-March 2006
Interim Project Report: January 2005
Critical Project Review: February 2005
Draft Project Final Report: January 2006
Final Project Report: May 2006
Approximate Cost: $150K

Task 1: Builder and Contractor Survey

Because the building industry is highly resistant to changes in building practice, the success of changes to building codes (in terms of both compliance and actual building performance) depends on their acceptance by the industry. To assist in this process, this task will determine builder and contractor concerns and issues regarding ventilation and IEQ and examine strategies for dealing with these concerns. The survey will include questions regarding incidences of ventilation related IEQ problems. The survey should include all the relevant issues including envelope construction methods, HVAC system locations, air tightness of envelopes, use of passive ventilation, use of mechanical ventilation, code compliance, recalls and repairs that can be related to ventilation issues, etc. The results of the survey will be used to assess the magnitude of IEQ and ventilation related concerns from the perspective of the building industry in California, and will show how changes in ventilation-related building practices could be made most smoothly with respect to the conservatism of the building industry (input to task Task 2).

Priority: Medium
Draft Report: June 2004
Final Report: September 2004
Approximate Cost: $100K

Task 2: Builder and Contractor Guidelines

Based on the survey results of Task1 and the technical results of other tasks, this task will develop guidelines for builders and contractors to help them select ventilation systems and provide them with technical and marketing information to overcome their concerns and issues. The guidelines will provide advice on issues such as climate-specific techniques, examples of how to meet code requirements and how to go beyond code requirements to meet the needs of sensitive populations.

Priority: Low
Draft Report: April 2005
Final Report: June 2005
Approximate Cost: $100K

Task 3: Development and Evaluation of Ventilation Systems

The objective of this task is to evaluate potential ventilation methods identified earlier in this scoping study. This task will require both field and laboratory testing. This task will produce equipment selection criteria based on climate, filtration requirements, noise and energy use, and also examine distribution issues. It is expected that sufficient information will be gathered that critical performance characteristics may be specified in the building code, for example: for ventilation fans a minimum efficiency in terms of cfm/W must be specified in the standard and this task will assist in determining exactly what value to use for this criterion. This task will look at optimizing performance for specific California climates and determining if new technologies are appropriate for use in California homes.

Task 3.1 Laboratory Technology Evaluation

Laboratory tests will be used to determine ventilation component and system performance under controlled conditions. The tests will evaluate the air flow, noise and energy consumption under a range of flow restrictions typical of those found in residential construction. The operating conditions studied should allow examination of specific problems known to afflict ventilation systems in houses, such as the effects of restrictive (and dirty) ducting. These tests will include a range of ventilation fans currently on the market, some air handler fans and passive devices. The air handler testing should include both ECM and PSC motors and the effects of restrictive cabinets on their performance.

Priority:	High
Draft Report:	September 2004
Final Report:	November 2004
Approximate Cost:	$200K

Task 3.2 Field Ventilation Technology Evaluation

A subset of ventilation strategies will be examined in a field study that will require diagnostics and monitoring. The diagnostic tests will be used to determine building envelope leakage and ventilation system performance in terms of air flow rates, noise, and pressure losses and power consumption. The monitoring will be used to determine whole house and buffer zone ventilation rates, and will also examine issues of distribution from room to room of ventilation air. A number of houses in a cross section of California climates need to be tested that incorporate the appropriate ventilation strategies for their individual climates. This field testing serves two purposes. It will provide a solid technical foundation for any specific technological requirements incorporated into Title 24 and it will provide case studies that will be used in the guidelines for Task 1

Priority:	High
Draft Report:	February 2005
Final Report:	April 2005
Approximate Cost:	$200K

Task 3.3 Emerging Technology Evaluation

The previous Tasks 3.1 and 3.2 focus on existing off-the-shelf technologies that already have a market presence. In order to provide information for the future direction of codes and standards we also need to look at systems that may become more readily available in the near future. If prototypes are available or can be easily assembled by LBNL we will perform the same laboratory evaluation as applied to existing technologies in Task 3.1. This task will also survey the state-of-the-art of ventilation systems in other countries that could be suitable for California (e.g., hybrid ventilation systems), and other relatively rare systems (e.g., continuous cleaning and filtration of indoor air instead of dilution with outdoor air).

Priority:	Medium
Draft Report:	April 2005
Final Report:	September 2005
Approximate Cost:	$100K

Task 4: Estimating Energy Use and Peak Demand

This task will examine in more detail the ventilation methods that are most appropriate for California housing and climates based on the work in Tasks 1 and 2 and consultation with the Commission. It will focus on computer-based modeling of the potential energy use and peak demand of various ventilation strategies. The modeling will need to explicitly include passive ventilation and window opening as well as mechanical systems. In addition, the links between ventilation systems and heating and cooling systems need to be accounted for. The calculations need to use short timesteps (on the order of one minute) to allow for accurate evaluation of intermittent systems.

The use of detailed computer models allows systematic variation of ventilation system parameters (such as air flow rate) and weather conditions so that the differences in ventilation system energy use and peak demand can be clearly evaluated.

Priority:	High
Draft Report:	February 2005
Final Report:	April 2005
Approximate Cost:	$150K

Task 5: Code Development

In order to build on the previous tasks, which focus on the technical and scientific basis for a standard and the impact of various ventilation options, this task focuses on the process of developing the ventilation code. The efforts in this task include 1) gathering input from constituents with interest in building energy codes 2) combining that input with the technical analyses to develop recommendations for changes to Title 24, 3) assisting the Commission during the public process.

In spring or summer of 2004 a workshop of interested parties will be held to better understand the needs and concerns of constituents with interest in building energy codes. At this workshop key issues will be presented and discussed.

After a critical project review the recommended code changes will be presented to the Commission in June 2005 for possible inclusion in the 2008 standards. Efforts will continue after that point to complete final reports. Effort is included in the proposed budget to make presentations, attend hearings and do a limited amount of follow-on analyses should questions be raised during the public process.

Priority:	High
Interested Parties Workshop:	June 2004

Memo report on status of and barriers to code changes: February 2005

Proposed Code Changes:	June 2005
Status Report on follow-on activities:	December 2005
Approximate cost:	$125K

Task 6: Technical Support for Compliance Tools

If code changes are to be adopted, the various code compliance calculation methods will also require technical changes. The purpose of this task is to provide technical assistance to the commission and compliance tool developers so that they can include any required changes in the compliance tools. This task will take the results of the field, laboratory and modeling tasks together with other research to determine appropriate algorithms, input data, required defaults, etc. that are needed for the compliance tools to account for the energy impact of the ventilation requirements of the code.

Effort is included in the proposed budget to make presentations, attend hearings and do a limited amount of follow-on analyses should questions be raised during the public process.

Priority:	Medium
Interested Parties Workshop:	June 2004
Memo report on status of and barriers to code changes:	February 2005
Proposed Code Changes:	June 2005
Status Report on follow-on activities:	December 2005
Approximate cost:	$150K

TECHNICAL PUBLICATIONS

Although not specifically mentioned in the list of deliverables, it is expected that each R&D-oriented task will result in at least one publication in the appropriate peer-reviewed scientific literature. These technical publications and any presentations associated with them are intrinsic parts of the technology transfer associated with this research.

SUMMARY

Our preliminary review indicates that it is feasible and advisable to modify the residential ventilation requirements in Title 24 in time for the 2008 standards cycle. This modification should be based on a well-focused research program that shows how to meet ventilation code requirements in an energy-efficient way. We have identified four research goals for this project:
Goal 1) ascertain the state of the art in residential ventilation technologies and strategies for California;
Goal 2) evaluate builder perspectives on value of and barriers to implementing new [new?] ventilation standards;
Goal 3) develop and test energy-efficient strategies and technologies for providing appropriate ventilation in California homes; and
Goal 4) provide technical support to the commission in developing code changes.

We have identified a number of key issues that must be addressed in this research including specific areas of improvement for ventilation systems, ease of code compliance, and development of new technologies. We have also evaluated existing technologies for the following: energy impacts, source control capabilities, peak demand, costs, additional market barriers or assets, durability and maintenance requirements, ease of inclusion in building design and construction, issues of meeting potential building code requirements, and impact on T24 algorithms.

To achieve the research goals and address the key issues we have proposed the following tasks:
Task 0) administration,
Task 1) builder and contractor survey,
Task 2) builder and contractor guidelines,
Task 3) development and evaluation of specific ventilation systems,
Task 4) estimating energy use and peak demand,
Task 5) code development, and
Task 6) technical support for compliance tools.
For each task we have established research priority, estimated costs, set timelines and outlined how each task may be performed.

The following is a summary of how the technical tasks are linked to the research goals.

Task 1: Builder and Contractor Survey
This survey will provide information on current ventilation strategies used by California builders that represent the current California state-of-the-art. This will contribute to goal number 1. The survey will provide the information on builders' perspectives for goal number 2. Lastly, questions will be asked of the builders regarding current code implementation and possible code changes that will contribute to goal 4.

Task 2: Builder and Contractor Guidelines
This task will provide guidelines for builders to make it easy for them to comply with any proposed code changes and persuade them to support code changes. This contributes directly to the technical support required to develop code changes for goal 4.

Task 3: Development and Evaluation of Ventilation Systems
This task directly supports goal 3 by developing and testing ventilation systems for California houses. The results of the testing in this task will provide technical information for supporting code changes for goal 4.

Task 3.1 Laboratory Technology Evaluation
The laboratory tests are needed to support goal 3 in order to systematically evaluate potential performance of ventilation systems under controlled conditions.

Task 3.2 Field Ventilation Technology Evaluation
The field evaluation will show how the potential performance evaluated in Task 3.1 translates into installed performance. This includes the vagaries of weather, and actual installation practice. This supports goals 3 and 4 by providing actual test data for developing appropriate ventilation and support for potential code changes.

Task 3.3 Emerging Technology Evaluation
New technology evaluation contributes to assessing the state-of-the-art for goal 1, and ensures that new and future California ventilation systems will reach their maximum potential in support of goal 3.

Task 4: Estimating Energy Use and Peak Demand
This task provides essential information for incorporating different ventilation systems into T24, and therefore supports goal 4. It also provides data in support of selecting between different strategies for goal 3.

Task 5: Code Development
This task supports goal 4 directly by providing code development assistance to the Commission.

Task 6: Technical Support for Compliance Tools
The purpose of this task is to provide technical assistance to the commission and developers of compliance tools so that they can include any required changes in the compliance tools in support of goal 4.

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