Consumer Non-Energy Benefits as a Motivation for Making Energy-Efficiency Improvements

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Few benefits are provided by electric power plants, coal mines, oil pipelines, or other energy supply systems aside from the energy they produce. Technologies to improve energy end-use efficiency, however, frequently offer non-energy benefits *beyond* those provided by supply-side options. One class of such benefits accrues at the national level—improved competitiveness, energy security, net job creation, environmental protection—while another relates to consumers and their decisionmaking processes. From a consumer perspective, it is often the non-energy benefits that motivate (or can be used to promote) decisions to adopt energy-efficient technologies. Consumer benefits can be grouped into the following categories: (1) improved indoor environment, comfort, health, and safety (2) reduced noise, (3) labor and time savings, (4) improved process control, (5) increased amenity or convenience, (6) water savings and waste minimization, and (7) direct and indirect economic benefits from downsizing or elimination of equipment. Consumer awareness of non-energy benefits is also relevant to utilities, energy service companies, and others seeking to sell efficiency. While energy-efficient technologies help provide *equivalent services* at lower costs, non-energy benefits can actually *add* value or enhance the energy services delivered by efficient technologies. In addition, where certain market segments are not sensitive to economic arguments (e.g., in the proverbial "landlord-tenant" split-incentive situation) non-energy benefits can assume special importance. From the perspective of energy consumers, non-energy benefits can equal or even exceed the importance of the energy cost avoided, thus meriting greater consideration in private investment decisions, marketing strategies, design and evaluation of utility programs, and government policies designed to promote energy efficiency. Specific technical examples are provided for highly efficient windows, energy-efficient lighting, and space conditioning, ventilation, and indoor air quality.

Introduction

Why Consider Non-Energy Benefits?

In this paper, we identify energy-efficient technologies that deliver equivalent energy service levels (compared to inefficient counterparts) and also offer non-energy benefits for consumers. Our thesis is that these benefits should be more strongly emphasized in technology assessment, marketing, and program evaluation activities.

Although direct economic benefits (cost-effectiveness) have been the mainstay in arguments for energy efficiency, amounting to as much as several hundred billion dollars of prospective annual savings at the national level, the relatively few dollars that a single consumer stands to gain don't provide as strong a motivation. In fact, it is often the non-energy benefits that motivate (or can be used to promote) decisions to adopt energy-efficient technologies. A striking example is the rapid penetration of microwave ovens into the housing stock over the past decade (Figure 1). While energy savings from microwave ovens can be substantial, the non-energy amenity and convenience factors appear to have driven consumer adoption.

The existence and consumer awareness of non-energy benefits is also important to utilities, energy service companies, and others seeking to "sell" efficiency by drawing attention to the collateral benefits. While it is common to speak of the ways in which energy-efficient technologies help provide *equivalent* services at lower costs, non-energy benefits can actually *add* value or otherwise enhance the energy services delivered by efficient technologies. In addition, where certain market segments are not sensitive to economic arguments (e.g., in the proverbial split-incentive "landlord-tenant" situation), non-energy benefits can assume a special importance.

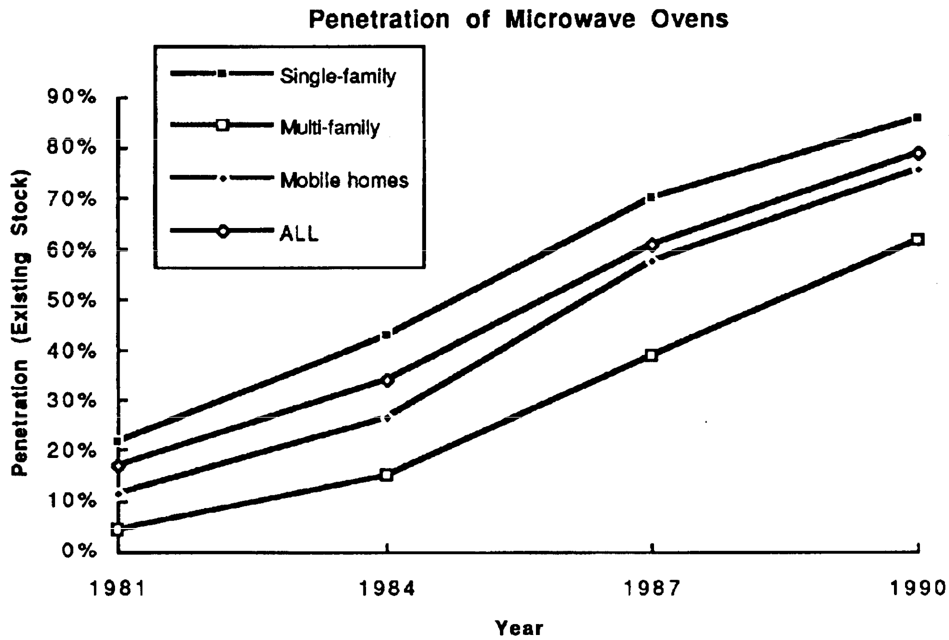

Figure 1. Market Penetration of Microwave Ovens in the U.S. Housing Stock (Hanford et al. 1993)

A Framework for Characterizing Non-Energy Benefits

Discussion of non-energy benefits often focuses on the societal level. Commonly cited examples of such benefits include enhanced energy security through reduced oil imports, job creation [considered a cost by economists], local economic development induced by large-scale efficiency programs, enhanced international competitiveness, and reduced pollution.

A different class of non-energy benefits emerge at the level of the individual energy consumer. Few efforts have been made to systematically describe and evaluate consumer non-energy benefits (see, e.g., Rashkin et al. 1993). Many documents have parenthetically noted individual items—or use non-energy benefits to promote a particular type of energy—but do not take a comprehensive view. Rashkin et al.'s effort to perform a literature search on non-energy economic benefits in buildings concluded that there are many data gaps and that further research is required. Non-energy benefits may defy economic quantification.

Seven categories of benefits are considered in this paper. Benefits are defined as improvements in a given category as compared with the attributes of the base-case (relatively inefficient) technology.

- *Improved indoor environment, comfort, health, and safety*— applies to measures that reduce indoor air pollution, enhance thermal comfort, or improve factors associated with health or safety, such as the ability of exhaust heat recovery systems to decrease the likelihood of insufficient ventilation rates at certain times of day or in certain parts of a building.

- *Reduced noise*— applies to measures that lead to reduced noise levels, such as the sound-insulating value of highly-efficient windows.

- *Labor and time savings*— applies to measures that have lower maintenance costs, improve productivity because workers have an improved environment, or reduce the amount of time required to do a task (exemplified by the more rapid cooking time offered by microwave ovens).

- *Improved process control*— applies to measures that enhance the control of a process, such as the use of variable-speed motors to improve quality and uniformity of a manufacturing procedure or halogen-lamp cooktops to improve control over cooking.

- *Increased amenity or convenience*— applies to measures that augment the quality of energy services or the functionality of the end-use device. For example, electronic ballasts eliminate flicker and noise from lighting systems.

- *Water savings and waste minimization*— applies to measures that lead to less water use, such as horizontal-axis clothes washers, or reduce waste of other resources.

- *Direct and indirect economic benefits from downsizing of equipment*— applies to measures such as HVAC equipment (direct) and distribution system (indirect) downsizing made possible as a result of reduced solar gain through windows, from lights and plug loads, etc.

The columns in Table 1 represent the attributes just described and indicate the existence of specific benefits for selected efficient end-use technologies. Note that some of the more popular efficiency technologies exhibit non-energy benefits in a number of categories (e.g., electronic ballasts and highly insulating windows). Table 2 provides brief descriptions of the benefits of the listed technologies.

The premise that non-energy benefits should be considered in energy planning rests on the validity of a total or

Table 1. Matrix of Non-Energy Benefits for Selected Energy-Efficient Technologies. (see Table 2 for descriptions of the bullets.)

	Improved Indoor Environment, Comfort, Health, Safety	Reduced Noise	Labor and Time Savings	Improved Process Control	Increased Amenity or Convenience	Water Savings and Waste Minimization	Direct and Indirect Economic Benefits (down-sizing)
Drivepower							
Variable-speed drives		•	•	•			
Efficient motors			•				•
Efficient belt drives	•		•				
Surfactant Additives		•	•				•
Lighting							
Halogen lamps			•		•		•
IR halogen lamps	•		•				•
Compact fluorescent lamps			•		•		•
Electronic ballast	•	•	•	•	•		•
CFL or LED Exit sign	•	•	•				•
Daylighting	•		•	•	•		•
Occupancy sensors	•		•		•		•
Windows							
Highly insulating windows	•	•			•		•
Solar-control glazings	•	•			•		•
Electrochromic glazings	•			•	•		•
HVAC							
Radiant cooling	•	•		•			•
Airvest	•	•	•				•
Exhaust heat recovery	•			•			•
Induced-draft furnaces	•	•					
Condensing furnaces	•	•					
Variable-speed furnace blower	•	•					
Appliances							
Horizontal axis clothes washer					•	•	
Low-flow showerhead, faucet						•	
Efficient dishwasher						•	
Microwave oven			•		•		
Microwave clothes dryer		•		•	•		
Efficient unvented appliances	•						
Other							
Envelope insulation	•	•			•		•
Laptop computer (compared to desktop)	•	•	•		•		•
Energy monitoring and control system	•		•	•	•		

Table 2. Matrix of Non-Energy Benefits for Selected Energy-Efficient Technologies

	Improved Indoor Environment, Comfort, Health, Safety	Reduced Noise	Labor and Time Savings	Improved Process Control	Increased Amenity or Convenience	Water Savings and Waste Minimization	Direct and Indirect Economic Benefits (downsizing)
Drivepower							
Variable-speed drives		quieter at lower speed	longer drive life	optimal speed can be chosen			
Efficient motors			longer life (cooler operation)				downsizing
Efficient belt drives	higher reliability		longer life				
Surfactant additives [low viscosity additive to reduce frictional and pumping losses in circulating fluids, e.g., in hydronic systems]		reduced chambering in pumps and pipes	reduced wear and tear on valves				pump downsizing
Lighting							
Halogen lamps			longer lasting than incandescent		distinctive light quality		HVAC interaction
IR halogen lamps	50x less UV radiation than standard halogen		longer lasting than incandescent				HVAC interaction
Compact fluorescent lamps			longer lasting than incandescent		cooler, less inconvenience and risk of injury during replacement		HVAC interaction
Electronic ballast	no perceptible flicker, facilitates daylighting and task/ambient VDT lighting	no hum	reduced lamp lumen depreciation	dimmability	smaller, lighter		HVAC interaction
CFL or LED Exit sign	less likely to burn out	no ballast hum if LED	longer lasting than regular exit signs				HVAC interaction
Daylighting	various health benefits		daylighting system longer lasting than luminaries	Can control illuminance with dimmable ballast	views, excellent color rendering		HVAC interaction
Occupancy sensors	outdoor security lighting		extends lamp service life in certain applications		automatic on/off switching		HVAC interaction
Windows							
Highly insulating windows	UV protection (eyes, skin) warmer surfaces; reduced condensation, possible EMI shielding, resists fire	sound barrier if more than one pane, low infiltration			UV protection for furnishings, artwork, textiles		HVAC interaction

Table 2. (Contd)

	Improved Indoor Environment, Comfort, Health, Safety	Reduced Noise	Labor and Time Savings	Improved Process Control	Increased Amenity or Convenience	Water Savings and Waste Minimization	Direct and Indirect Economic Benefits (downsizing)
Windows (contd)							
Solar-control glazings	UV protection	sound barrier if more than one pane, low infiltration			UV protection for furnishings, artwork, textiles		HVAC interaction
Electrochromic glazings	window can be made opaque for privacy			dynamically tunable transmittance	reduced glare, possible EMI shielding, resists fire		HVAC interaction
HVAC							
Radiant cooling	enhanced thermal comfort	no ventilation noise		better control of thermal environment			reduced space required for ventilation system
Airvest [small, low-power fan worn on chest of worker in spray booth]	reduced worker exposure to air-borne chemicals	decreased ventilation rate	improved worker health				decreased fan capacity
Exhaust heat recovery	lower probability of insufficient air change rates			improved control over air circulation and exchange rates			HVAC interaction
Induced-draft furnaces	safer; reduced probability of backdrafting and spillage of pollutants	quieter operation					
Pulse combustion, condensing furnaces	safer with sealed combustion	quieter operation					
Variable-speed blower on furnace	less drafts	quieter operation					

societal resource cost test. Ignoring any component (cost or benefit) violates this test. We recognize that when improperly applied, energy-efficient technologies may not maintain energy service levels and can have other undesirable side-effects (e.g., light quality or noise problems that can occur with compact fluorescent lamps). It is not the aim of this paper to evaluate such impacts. Here, we have focused on one particular component (non-energy benefits) that is not well understood. Furthermore, the task of evaluating non-energy costs would be more complicated than the one at hand, because corresponding side-effects on the energy supply side would also have to be estimated for comparison. For example, evaporative coolers; water consumption would have to be reconciled with the amount of water conceivably not consumed by for cooling towers in electric power plants producing the electricity to operate refrigerative air conditioners. Non-energy *benefits,* on the other hand, are difficult to identify for energy supply technologies (aside from employment and the environmental harm avoided by renewable). Consumer-specific benefits are even rarer.

Detailed Examples

In the following section, we profile some of the technologies shown in Table 1, and provide detailed examples of the non-energy benefits. Many other examples could be given.

Highly Insulating Windows

Energy-efficient windows offer a wide array of non-energy benefits. If the attention given to them in the trade literature and advertising is an indication, the window industry believes these benefits are crucial to consumer adoption. Highly insulating windows are among the most successful energy-efficiency technologies. Today, for example, low-emissivity windows represent about 42% of new residential window sales and 21% of commercial building sales.

Non-energy benefits for windows include reduced transmission of radiation that causes fading, and improved thermal comfort (discussed below). Low-emissivity and electrochromic windows may also provide shielding against electromagnetic radiation that can interfere with electronic devices such as wireless communications equipment and inhibit electronic spying. Efficient windows make homes safer in the event of fire. Double-glazed windows were cited as one reason that a home survived a fire in which virtually every other home in the neighborhood was destroyed (Fleeman 1993). Thermal shock due to the expansion of the window panes causes some of the outer panes to shatter—providing a point of entry for the fire into the home—but the interior panes remain intact. Reduced condensation can be achieved via reduced thermal conductivities and lack of thermal bridges in the window frame, Reduced sound transmission is another benefit offered by multiple panes of glass (and thicker glass) or reduced infiltration around windows. Efficient glazing systems provide effective acoustical insulation (Figure 2).

Reduced Damage to Furnishings [Coatings to filter damaging wavelengths]. Most efficiency options for windows decrease the transmission of destructive radiation. This radiation can damage home furnishings, artwork, etc. Damage (defined here as change in coloration) increases exponentially with increasing frequency and is most severe in the UV spectrum, but can be caused by radiation that extends well into the visible range. Each pane of glass filters some of the damaging wavelengths, so even double-glazed windows are an improvement over single-glazed ones. Low-emissivity coatings offer additional reductions. Figure 3 presents the solar spectrum, the damage function for textiles, and the transmission spectra of several increasingly efficient glazing systems. Note that UV transmission for efficient glazings virtually disappears above 350 nanometers-the border of UV radiation. As an overall weighting (i.e., average index of damage for a variety of materials), single-glazing results in a value of 0.74, double-glazing 0.62, double-glazing with a low-e coating 0.33, and the superwindow 0.19. Some people also have visual and dermal sensitivity to UV radiation, and their exposure would probably be reduced by efficient windows.

Enhanced Thermal Comfort [Warmer inner glass winter temperatures, cooler summer ones]. Energy-efficient windows also enhance thermal comfort. Window temperatures contribute to a building's overall mean radiant temperature (MRT), a weighted average temperature of building surfaces that can "see" a given human occupant. Single-glazed windows will result in interior glass surface temperatures close to outdoor temperatures and will contribute to producing winter (summer) MRTs that are lower (higher) than the interior air temperature. This situation contributes to thermal discomfort both in hot and cold climates.

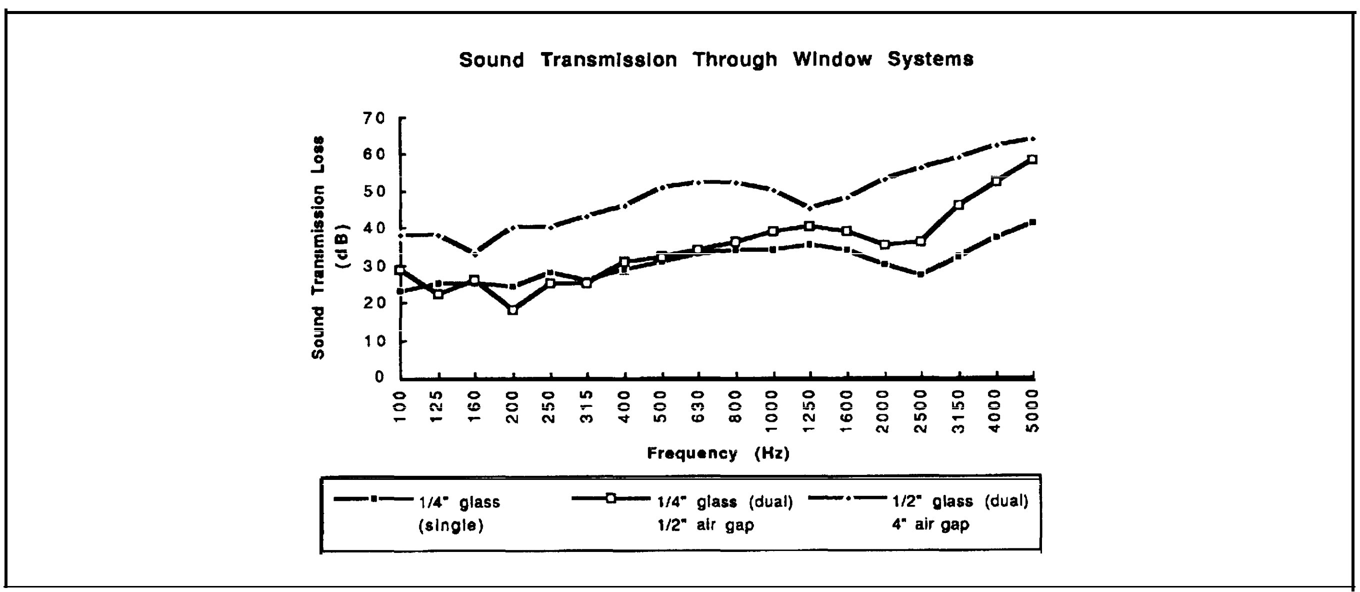

Figure 2. Acoustical Properties of Various Window Systems

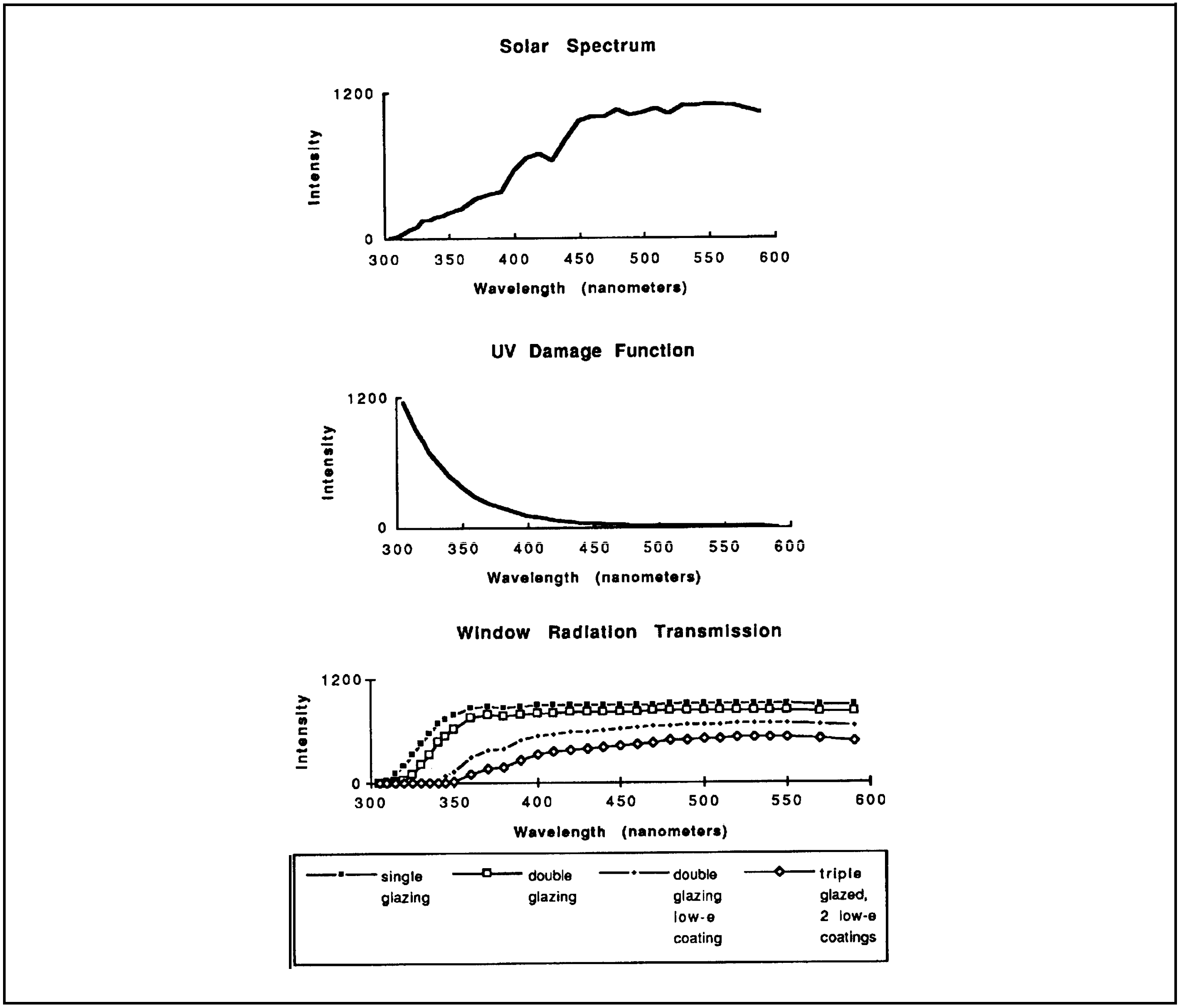

Figure 3. Damage is Highest at the UV (leftmost) End of the Spectrum, Much of Which is Filtered by Efficient Glazings

Part of the problem stems from two conflicting standards. For thermal comfort, ASHRAE Standard 55-1992 (Thermal Environmental Conditions for Human Occupancy) recommends that radiant asymmetry in the horizontal direction should not exceed 10°C (18°F) for subjects standing two feet from a window. For energy efficiency, ASHRAE Standard 90.2, recommends window U-values of 0.87 (R 1.1) for much of the southern and eastern United States. St. Louis and Washington DC are among the colder cities in this region.

The ASHRAE recommended thermal performance can be achieved by a single-glazed window in a vinyl frame. For the comfort standard, if all other surfaces in the room are 21°C (70°F), the glass temperature must not fall below 7.8°C (46°F) if comfort is to be maintained. As shown in Figure 4, this discomfort condition will occur for 1100 hours during the heating season (22% of the hours) for a south-facing single-glazed window in St. Louis. With double glazing and a 1/4-inch airgap, the number of annual discomfort hours drops to 35 (<1% of the hours).

The figure shows the distribution of total non-setback heating hours that the interior surface temperature of window glass is within each temperature bin. The results were derived using DOE 2.1 E for a single-family dwelling in St. Louis, Missouri. Only those hours between 6am and midnight and during the assumed heating season of September 1 through May 31 (4914 hours/year) are included. This example is for a south-facing window. Approximately the same condition holds for east, north, and west orientations.

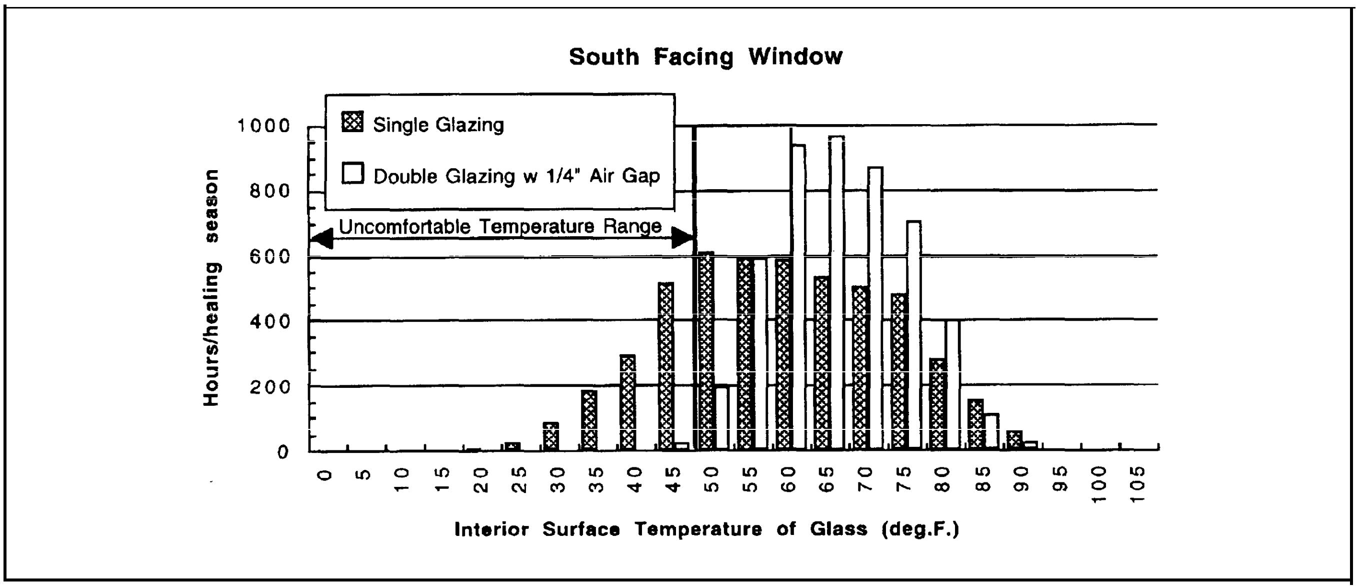

Figure 4. Comparative Indoor Comfort Conditions for Single Verses Double Glazing in St. Louis

Energy-Efficient Lighting

Of all end uses, efficient lighting technologies have perhaps the highest incidence of non-energy benefits. The benefits exist in the areas of enhanced visual environmental factors, labor productivity, and various amenities. In fact, one of the (non-energy) factors that helped create the market for electric lighting a century ago was the greatly reduced fire hazard offered by electric versus gas lights. Modern efficient lighting technologies can go a long way towards reducing glare and enabling better visual performance, while generating significant indirect HVAC energy use and capital-cost savings.

Increased Light Quality and Longevity [Halogen, CFL, LED Light Sources]. The rapid increase in popularity of energy-saving halogen lamps in homes and businesses is a striking modern-day case in point of how new energy-efficient technologies can be propelled into the market by factors other than their energy-saving qualities. The energy-saving benefits are overshadowed in the minds of most consumers by the light quality (directionality, sparkle) provided by halogen sources. Halogen luminaires have distinguished themselves in the marketplace by assuming the status of high-end furniture (rather than “lamps” purchased strictly for their functional value).

Exit signs fitted with compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) are other examples of energy-efficient lighting technologies that offer non-energy benefits (Tucker 1992). Both of these light sources last much longer than the incandescent lamps they are designed to replace. This translates not only into labor and materials savings but also into an increased likelihood that the signs will be operating properly in a time of need—burned-out incandescent exit signs are an uncomfortable common sight. The market share of CFL exit signs has already reached 100% in several European countries (Mills 1993). The longer life of CFLs also has shown value in the residential sector. Rebate programs in Sweden found that senior citizens were more heavily represented among lamp buyers (~30% of the total) than their share of the general population, presumably because of the greatly reduced inconvenience and risk of falling during lamp changes, among other factors (Mills 1993). The labor costs of lamp changes in some environments (stairwells, high-security areas, etc.) can be quite high.

Benefits for Health [High-frequent y Ballasts and Daylighting]. High-frequency electronic ballasts—one of the most successful energy-efficient technologies—offer numerous non-energy benefits, spanning most of the categories in Table 1. By virtue of their non-flickering operation, electronic ballasts probably have positive health impacts compared to standard magnetic ballasts (Wilkins 1991). For example, in a double-blind study in the United Kingdom, office workers with high-frequency ballasts had less than half the incidence of headaches and eyestrain as their co-workers in offices with normal 50-Hz ballasts. The irrational and overwhelming fear of public places (agoraphobia) and other manifestations of anxiety have also been observed to diminish when subjects switch to high-frequency lighting. At frequencies at or below 60Hz, flickering light can trigger epileptic seizures in sensitive individuals.

Daylighting (facilitated by electronic ballasts linked to photocells) is another energy-saving lighting strategy that has many desirable non-energy attributes. According to a review of recent research cited by Wilkins (1991), people prefer to work by daylight, and the absence of windows has been correlated with an increase in transient psychosis in hospitals and an increase in absenteeism in schools and factories. In humans, levels of melatonin appear to be influenced by light and may help explain seasonal affective disorder (SAD), a type of psychological and physiological depression that affects about 5% of the population.

Space Conditioning, Ventilation, and Indoor Air Quality

While indoor air quality and energy efficiency have often been simplisticly portrayed as mutually exclusive, various field studies have found complex correlations between ventilation rates and indoor concentrations of pollutants such as radon, formaldehyde, respirable suspended particles, polycyclic aromatic hydrocarbons, nitrogen dioxide, carbon monoxide, carbon dioxide, and water vapor (Turk et al. 1987a,b; Turk et al. 1988). There are in fact cases in which improvements in efficiency lead to reductions in indoor pollutants. Moreover, extremely energy-efficient air-handling is consistent with superlative indoor air quality if properly designed and controlled. Modern control options include real-time measurement of CO2, CO, formaldehyde, and other pollutants.

Reducing Contaminants from Unvented Combustion Appliances [Gas Cooking]. An unvented combustion appliance (e.g., some stovetops and kerosene heaters) will introduce fewer pollutants to the indoor environment if it operates efficiently. As an extreme example, poorly-controlled central heating in multi-family units may drive tenants to use their cooktops for space heating. This was documented for three public housing authorities, where monthly gas usage was up to five times higher in winter in buildings where central space and water heating was provided by oil-fired boilers (Greely et al. 1987). In one location (400 housing units), heating control valves and steam traps were installed to save energy, and-as a side effect—the seasonal fluctuation of cooking gas consumption decreased about three-fold compared to peak pre-retrofit levels (Figure 5). Reduced release of gas combustion products into these apartments is a potentially important non-energy benefit of the heating controls retrofit.

Eliminating Backdrafting and Spillage of Combustion Products [Advanced Furnaces]. Advanced furnaces offer particular indoor air quality benefits. In furnaces that rely on a thermally-induced stack effect to transport combustion products through the flue and outside the structure, certain outdoor conditions (temperature or wind) can cause backdrafting and spillage of pollutants into the living space. This problem can also be triggered by other ventilation devices in a home (e.g., stovetop or bathroom fans), which create a negative pressure across the building envelope. Efficient forced-draft furnaces can counteract these effects. Condensing combustion furnaces eliminate the need for a stack altogether.

Improved Ability to Reduce Airborne Contaminants [Heat-Recovery Ventilation]. The two hypothetical homes shown in Figure 6 (with and without heat-recovery ventilation) have comparable annual *average* air change rates of about 0.5 air changes per hour (ach), but the scatter is much wider in the home without mechanical ventilation, and a large number of hours occur with rates considered low. For the naturally ventilated home, there are 600 hours per year that the ventilation rate is under 0.25 sch. For the mechanically ventilated home, there would be no severe under-ventilated periods as long as the system is on.

Heat-recovery ventilation can help avoid brief periods of low ventilation rates that can cause high concentrations of indoor pollutants (Wallman et al. 1987). Not only is this of value in reducing exposure to indoor pollutants, but it also can reduce the likelihood of damaging water vapor levels. Problems with elevated water vapor levels in bedrooms were lower in the heat-exchanger homes monitored by Turk et al. (1987b) than in a group of control homes. There were more complaints about mold and mildew in control homes than in efficient homes (Vine 1987). The air-to-air heat exchangers achieved better mixing of air.

Reduced Spraybooth Ventilation and Pollutant Concentrations [The Airvest]. Spray booths are a common sight in industrial buildings. Designed to remove pollutants during processes such as spray painting or welding, a spray booth is open on one side where the worker stands, and equipped on the opposite wall or ceiling with a fan and filter arrangement to exhaust contaminated air. However, during standard operation, pollutants become trapped in the eddy that forms immediately downwind of the worker and then rise into the worker's breathing zone. A new energy-saving invention known as an "airvest" consists of a little fan box worn on the chest of a spray booth worker (Gadgil et al. 1993). The low-power fan ventilates or eliminates the eddy. Measurements using smoke and a mannequin show reductions of contaminants in the breathing zone of 100- to 800-fold, depending on how much air is ejected from the box. With the airvest, it appears possible to substantially reduce the fan speed in the spray booth. Reduction of the flow rate by a factor of two will result in net savings of roughly $1000 per shift per booth each year from reduced heating, cooling, and filtration of the incoming make-up air. This reduction in energy accompanies a 50-fold reduction in the workers exposure to pollutants generated in the booth (Figure 7).

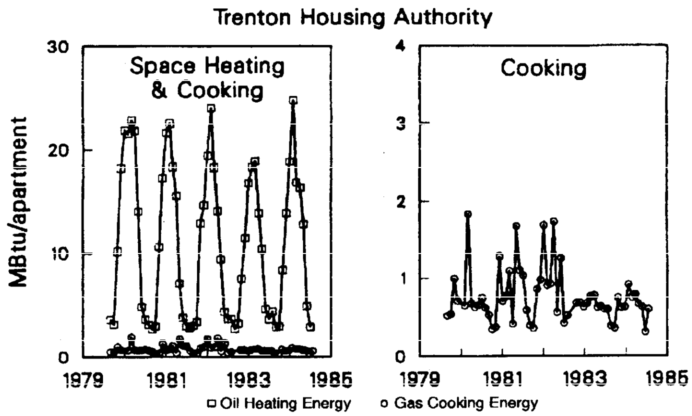

Figure 5. Seasonally of Cooking Fuel Use Decreased Markedly Following a Heating Controls Retrofit in the Trenton Housing Authority; Oil Use Includes Space and Domestic Water Heating (Greely et al. 1987)

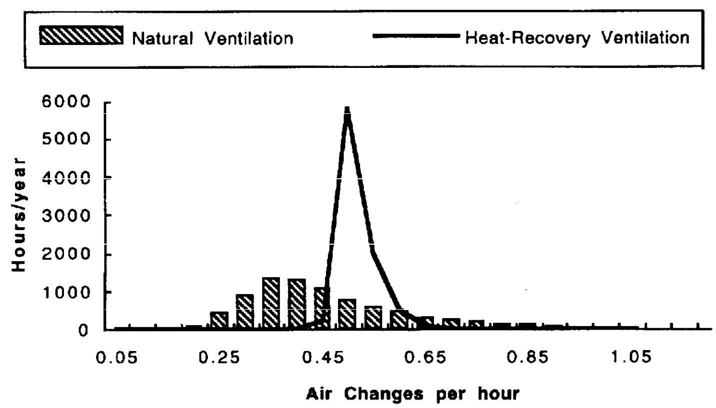

Figure 6. Comparative Distributions of Ventilation Rates in Homes With and Without Heat Exchangers in the Exhaust Air System (Wallman et al. 1987)

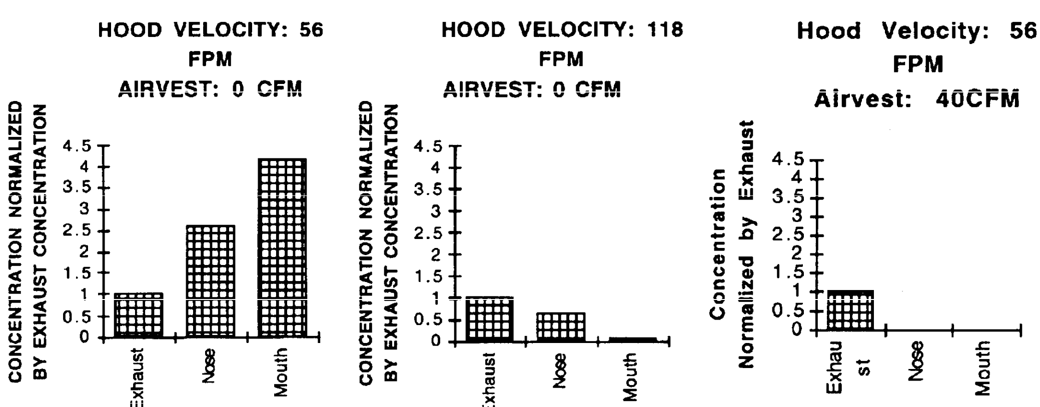

Figure 7. Spray-Booth Exposures Without the Airvest (left); a Higher Booth Exhaust Velocity (center); and the Airvest (right) FPM = feet per minute, CFM = cubic feet per minute (Gadgil et al. 1993)

Decoupling Ventilation from Space Conditioning [Economizer Cooling and Radiant Cooling]. Radiant cooling, a strategy widely used in Europe but little known in North America, achieves energy savings by separating the tasks of providing cooling and fresh air. In a radiant cooling system, cold water is circulated through ceilings, both cooling the air and creating a reduced mean radiant temperature in the occupied space. Outside air can be provided separately (at 80 to 90% lower volumes, since heat transfer is not an objective) and recirculation is unnecessary. Energy savings are achieved because transporting coolth by pumping water is much less energy-intensive than using air. In addition to substantial energy savings, non-energy benefits of radiant cooling include avoiding the spread of odors or other airborne contaminants through the building, less likelihood of drafts and noise due to lower volumes of air movement, and reduced space requirements for the ventilation system. Thermal comfort will be enhanced because the radiant temperature of large ceiling areas will be low (Feustel 1993).

Strategies that save energy while reducing the amount of recirculated air (e.g., with radiant cooling or economizer cooling) may play a role in eliminating certain pathways of disease transmission. Evidence comes from a controlled study that compared the incidence of febrile acute respiratory diseases (cold with a fever, caused by viral infection of the lungs) in army trainees in two sets of barracks (Brundage et al. 1988). HVAC systems in the “modern” barracks recirculated approximately 95% of the air and provided three air changes per hour. In the “old” barracks, windows and ceiling exhaust fans were the primary source of ventilation, and the HVAC systems recirculated only 50% of the air. During 2.6 million trainee-weeks in the 1982-1986 period, there were more than 14,000 acute respiratory disease hospitalizations among soldiers living in the two sets of barracks. The ratio of new-to-old barrack hospitalization rates was 1.51:1, translating into about 2,700 more admissions among occupants of the barracks that used predominantly recirculated air.

Decreasing Friction Losses in Closed-Loop Water Systems [Surfactant Additives (“Slippery Water”)]. The pumping energy required for hydronic space conditioning systems and other systems for circulating fluids is dependent on the amount of friction in the pipes and components (e.g., heat exchangers and pumps). A new frontier for saving energy in closed-loop systems in buildings involves adding surfactants to the circulating fluid to reduce friction losses. Recent research results suggest a great potential for energy savings and for non-energy benefits (Gasljevic, K. et al. 1991; Gasljevic and Matthys 1992; personal communication: Eric Matthys, U.C. Santa Barbara). Friction reductions of 60 to 80% have already been demonstrated. Experiments have shown less cavitation (small bubbles formed by local boiling, that collapse noisily), especially in pumps. In addition to creating noise, cavitation is also destructive to pumps and other hardware. Decreased friction leads to less vibration in pipe networks and a lower power requirement for pumping, possibly prolonging pump life (e.g., if pumps are used with variable-speed drives to enable speed control). Alternatively, because many existing hydronic systems are under-designed, the addition of surfactants can increase the capacity or performance of an existing system. Since the greatest electricity savings will tend to occur during peak conditions, it is reasonable to expect that friction reductions will lead to reduced equipment failure and wear and tear on hydronic systems. Surfactants may also decrease corrosion rates in pipes.

Incorporating Non-Energy Benefits into Efficiency Resource Acquisition

If we acknowledge the existence of non-energy benefits, then policymakers should consider ways of incorporating these benefits into the energy planning process. To some extent, this is already being done. For example, carbon taxes on energy have been implemented by some nations, and frameworks for incorporating environmental externalities into cost-effectiveness calculations are planned at a number of utilities. However, these illustrations are concerned mostly with the national or international dimension rather than the decision environment of individual consumers. Of course, decision making in certain consumer segments is influenced by environmental and other “societal” considerations.

Some preliminary efforts have been made to advance non-energy benefits more carefully. The Swedish National Board for Technical and Industrial Development, for example, calls for quiet refrigerators and 1ow-EMF ballasts in its “Technology Procurement” programs (Lewald and Bowie 1993).

There are also prospects for the insurance industry to recognize non-energy benefits. Buildings that incorporate energy-efficient technologies that in some fashion enhance safety or otherwise preserve property values could be awarded with lower insurance premiums. Specific examples include fire-resistant features (light paints, dual-glazed windows) or insulation (attic insulation reducing the probability of ice dams or pipe insulation reducing likelihood of pipe breakage and water damage to the home).

Energy Planning Considerations

Vine and Harris (1989) suggested extending conservation supply-curve analysis (in which efficiency options are ranked according to increasing cost of conserved energy) to non-energy factors. Environment, job creation, and other quantifiable benefits can be ranked and organized. This approach could be useful for public policy decision-makers, but is not well-suited for consumers. Moreover, the approach would be difficult to apply to many of the factors outlined in this paper, e.g., supply curves of increased comfort are hard to imagine.

In the case of utility sponsored conservation programs, the existence of non-energy benefits argues for considering more than a simple utility cost test when assessing the cost-effectiveness of various conservation measures. In Washington State, non-energy benefits have been considered in proceedings before the Washington Utilities and Transportation Commission in the context of cost-effectiveness tests employed by both Puget and WWP. In both instances, the issue was how to ensure that utility conservation programs were cost-effective considering the payments made by the utility for energy savings and the payments made by the participant for both energy *and* non-energy benefits. The existence of both energy and non-energy benefits meant that, from a total cost and total benefit perspective, the utility should be able to offer measures that are not cost-effective from a utility energy perspective alone. However, some means was necessary to ensure that the total paid for energy savings by the utility together with its participant did not exceed the value of *energy* savings. While all parties agreed that the total resource cost (TRC) test was the appropriate test for determining overall cost-effectiveness, they also agreed that it was impossible to perform this test, and that it was inappropriate to place the utility, the regulatory agency, or the state in the position of determining the value and legitimacy of non-energy benefits.

Consequently, both Washington Water Power and Puget Power were granted permission to provide funding for conservation measures that cost *more* than the utility's avoided cost, but only so long as the utility funding did not exceed a utility cost test adjusted to reflect the estimated value of energy savings to the participant (basically two years energy savings). This adjustment only applies to measures which cost more than the utility's avoided cost. While the WWP and Puget funding formulae vary slightly, they are both intended to ensure that the utility and its customer do not jointly pay more for energy savings than the value of those savings, and that the marketplace freely establishes the value of non-energy benefits.

An added reason for energy planners to assess non-energy benefits more fully is the current lack of standardization in how those benefits are measured. This leads to conflicting consumer information and dubious claims in product literature. Conflicting claims about UV protection and noise shielding in window advertisements are a case in point.

Conclusions

The evidence presented here suggests that many non-energy benefits that can play a role in consumer perceptions of energy-efficient technologies. Some of the most successful technologies to date (microwave ovens, electronic ballasts, energy-efficient windows) are among those with the most non-energy benefits. Greater recognition of non-energy benefits, and efforts to make them more prominent in program design and marketing, will help accelerate the uptake of energy-efficient technologies.

Further work could focus on gathering more data and case studies, integrating non-energy benefits into DSM marketing and other efforts to promote efficient technologies, and special consideration of developing countries. Other sectors (industry, transport, and agriculture) should also be examined.

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References

Brundage, J. F., Robert, S., Lednar, W. M., Smith, D. W., and Miller, R. N. 1988. "Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees." *Journal of the American Medical Association* (259)14:2108-2112.

Feustel, H. 1993. *Hydronic Radiant Cooling—Overview and Preliminary Performance Assessment,* Lawrence Berkeley Laboratory, Report No. 33194.

Fleeman, M. 1993. "A Smart Home Survives Disaster." San Francisco Examiner, Friday, October 9, page A-20.

Gadgil, A. J., Faulkner, D., and Fisk, W. J. 1993. "Reduced Worker Exposure and Improved Energy Efficiency in Industrial Fume Hoods Using an Airvest." Proceedings, 'IAQ'92: Environments for People,' pp. 293-300. October 19-21, 1992, San Francisco, CA.

Proceedings published by ASHRAE, Atlanta, GA. Also available as Lawrence Berkeley Laboratory Report LBL-32244 (1992).

Gasljevic, K., and Matthys, E. F. 1991. "A Feasibility Study of the Use of Drag-Reducing Additives to Reduce Pumping Power in Hydronic Thermal Distribution Systems." In *Industrial Applications of Fluid Mechanics* (T. Morrow, L. Marshall, and S. Sherif, eds.). FED-132:57-65, New York: American Society of Mechanical Engineers.

Gasljevic, K., Jaroux, B., and Matthys, E. F. 1992. "Effect of Drag-Reducing Surfactant Solutions on Centrifugal Pump Performance." In *Recent Advances in Non-Newtonian Flows* (D. Siginer, cd.) FED-141:49-56, American Society of Mechanical Engineers.

Greely, K. M., Mills, E. Goldman, C. A., Ritschard, R. L., and Jackson, M. A. 1987. *Baseline Analysis of Measured Energy Consumption in Public Housing.* Lawrence Berkeley Laboratory, Berkeley, California, Report No. 22854.

Hanford, J. W., Stewart, L. E., Lecar, M. E., Johnson, F. X., Hwang, R. J., and Koomey, J. G. 1993. *Baseline Data for the Residential Sector and Development of a Residential Forecasting Database.* Lawrence Berkeley Laboratory Report No. LBL-33717 (Draft).

Lewald, A. and Bowie, R. 1993. *What is Happening with the Swedish Technology Procurement Program ? A Condensed Version of the Procurement Program's First Process and Impact Evaluation.* Proceedings of 1993 ECEEE Summer Study on Energy Efficiency in Buildings, The European Council for an Energy-Efficient Economy, Oslo, Norway, pp. 81-94.

Mills, E. 1993. "A Graceful Exit." *IAEEL Newsletter, 3/93*, Stockholm, Sweden.

Mills, E. 1993. "Efficient Lighting Programs in Europe: Cost-Effectiveness, Consumer Response, and Market Dynamics." *Energy–The International Journal* (18)2; 131-144.

Rashkin, S., Nylund, E., Grahm, J. 1993. "Reducing Utility DSM Program Costs by Promoting Non-Energy Benefits of Energy-Efficiency and Solar Technologies." Proceedings: 6th National Demand-Side Management Conference, pp. 277-281. Electric Power Research Institute, EPRI TR-102021.

Tucker, R. A. 1992. "Energy Efficient Lighting and Security: Are They Compatible?" *Energy Engineering,* (89)2:32-35.

Turk, B. H., Brown, J. T., Geisling-Sobotka, K., Froehlich, D. A., Grimsrud, D. T., Harrison, J., Koonce, J. F., Prill, R. J., and Revzan, K. L. 1987a. *Indoor Air Quality Ventilation Measurements in 38 Pacific Northwest Commercial Buildings.* Lawrence Berkeley Laboratory Report Nos. 22315 1/2 and 2/2.

Turk, B. H., Grimsrud, D. T., Harrison, J., and Prill, R. J. 1987b. *A Comparison of Indoor Air Quality in Conventional and Model Conservation Standard New Homes in the Pacific Northwest: Final Report.* Lawrence Berkeley Laboratory, Berkeley, California. LBL-23429.

Turk, B. H., Grimsrud, D. T., Harrison, J., Prill, R. J., and Revzan, K. L. 1988. *Pacific Northwest Existing Home Indoor Air Quality Survey and Weatherization Sensitivity Study.* Lawrence Berkeley Laboratory Report No. 23979.

Vine, E. 1987. *Air-to-Air Heat Exchangers and the Indoor Environment.* Lawrence Berkeley Laboratory Report No. 22908, Berkeley, California.

Vine, E. and Harris, J. 1989. Evaluating Energy and Non-Energy Impacts of Energy Conservation Programs: A supply Curve Framework of Analysis. *Energy* (15)1:11-21.

Wallman, P. H., Pedersen, B. S., Mo, R. J., Fisk, W. J., and Grimsrud, D. T. 1987. "Assessment of Residential Exhaust-Air Heat Pump Applications in the United States." *Energy* (12)6:469-484.

Wilkins, A. J. 1991. "Health and Efficiency in Lighting Practice." *Energy* (18)2: 123-129.