Indoor Environmental Quality and Climate Change

Prepared for:
The Indoor Environments Division
Office of Radiation and Indoor Air,
U.S. Environmental Protection Agency

Prepared by:
Terry Brennan
Camroden Associates

Indoor Environmental Quality and Climate Change

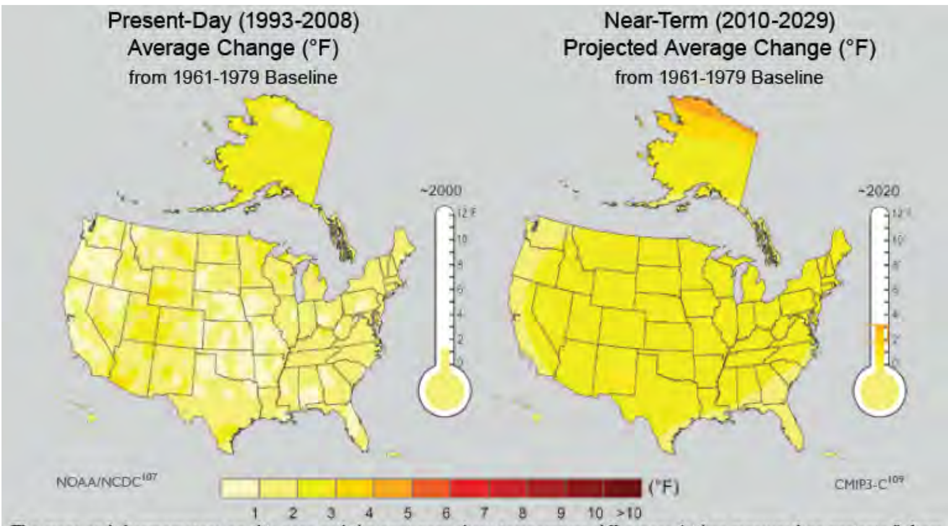
Expected Climate Changes

The expected climatic changes considered in this paper are taken from the U. S. Global Change Research Program's 2009 report "Global Climate Change Impacts in the United States" (CCSP 2009). They include:

- Temperature:
  - Overall the earth is expected to warm over the next century. Surface temperatures throughout the U.S. are expected to increase (Figures 1 and 2).
  - The number of Heating Degree Days (HDD) in the U.S. is expected to decline and the number of Cooling Degree Days (CDD) is expected to increase (Figure 3).
- Precipitation:
  - Some locations will become dryer, others wetter:
    - A number of areas are predicted to have decreased annual rainfall (Figure 4) including the Northwest, the Southeast, Arizona and Southern California.
    - A number of states are predicted to have increased rainfall (Figure 4). Particularly the Northeastern states and the northern Mid-Atlantic states.
    - Increases and reductions in annual rainfall are not expected to be uniform (Figure 5). For example, Southeastern states are predicted to become dryer overall, but Florida and southern Alabama, Mississippi and Louisiana are predicted to be wetter in the fall due to hurricane activity.
- Severe weather events may become frequent or more severe:
  - There will be more days hotter than 90°F (Figure 6).There will be more extremes in rainfall (Figure 7).There will be increases in the frequency and intensity of hurricanes, tornadoes, ice storms and snow storms, and consequent floods and loss of electric power (Figure 8).
- Rising sea level

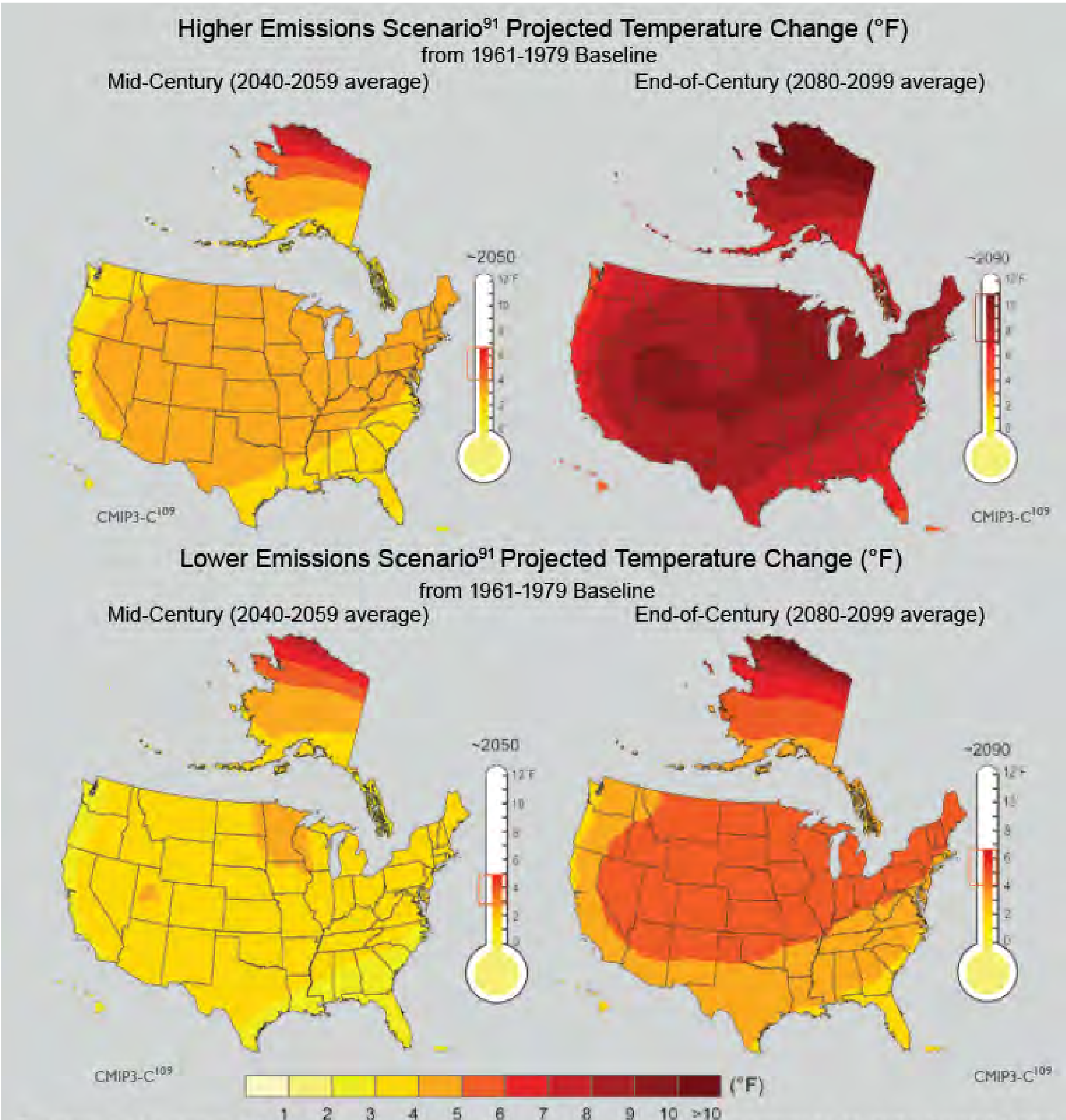
Green House Gases in the Atmosphere Drive Climate Change

"Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. These emissions come mainly from the burning of fossil fuels (coal, oil, and gas), with important contributions from the clearing of forests, agricultural practices, and other activities" (CCSP 2009 page 9).



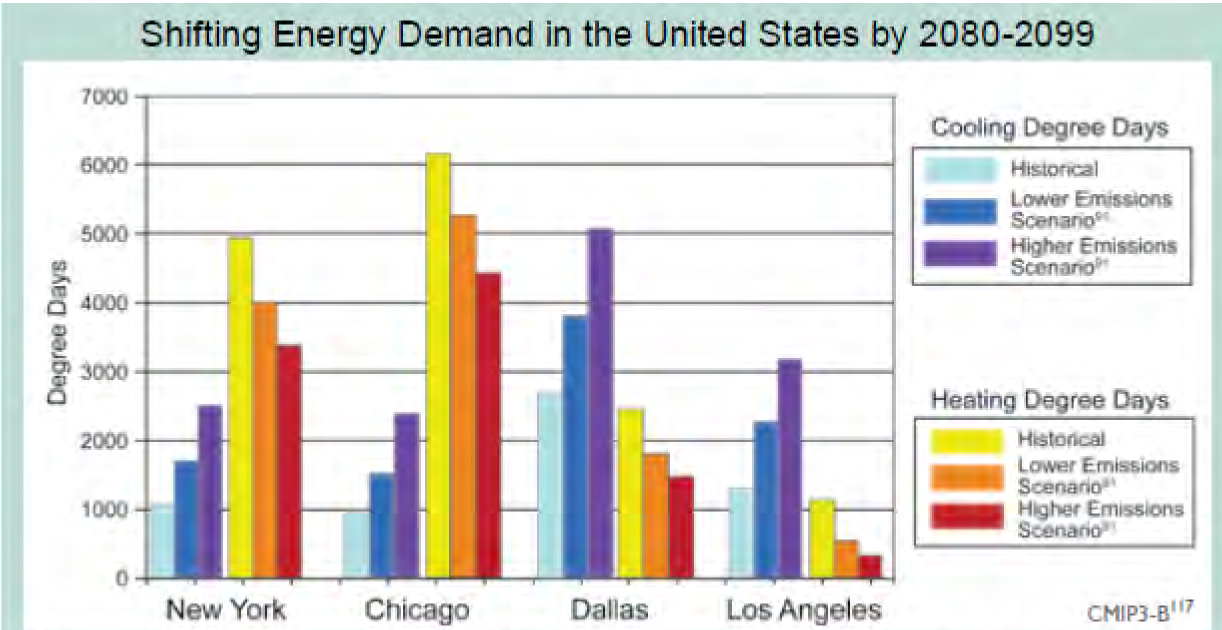
The maps and thermometers on this page and the next page show temperature differences (either measured or projected) from conditions as they existed during the period from 1961-1979. Comparisons to this period are made because the influence on climate from increasing greenhouse gas emissions has been greatest during the past five decades. The present-day map is based on the average observed temperatures from 1993-2008 minus the average from 1961-1979. Projected temperatures are based on results from 16 climate models for the periods 2010-2029, 2040-2059, and 2080-2099. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. The mid-century and end-of-century maps show projections for both the higher and lower emission scenarios.[91] The projection for the near-term is the average of the higher and lower emission scenarios[91] because there is little difference in that timeframe.

Figure 1



The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).[91] The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is on pages 22 and 23 in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at national, regional, and sub-regional scales, using well-established techniques.[110]

Figure 2



"Degree days" are a way of measuring the energy needed for heating and cooling by adding up how many degrees hotter or colder each day's average temperature is from 65°F over the course of a year. Colder locations have high numbers of heating degree days and low numbers of cooling degree days, while hotter locations have high numbers of cooling degree days and low numbers of heating degree days. Nationally, the demand for energy will increase in summer and decrease in winter. Cooling uses electricity while heating uses a combination of energy sources, so the overall effect nationally and in most regions will be an increased need for electricity. The projections shown in the chart are for late this century. The higher emissions scenario[91] used here is referred to as "even higher" on page 23.

Figure 3

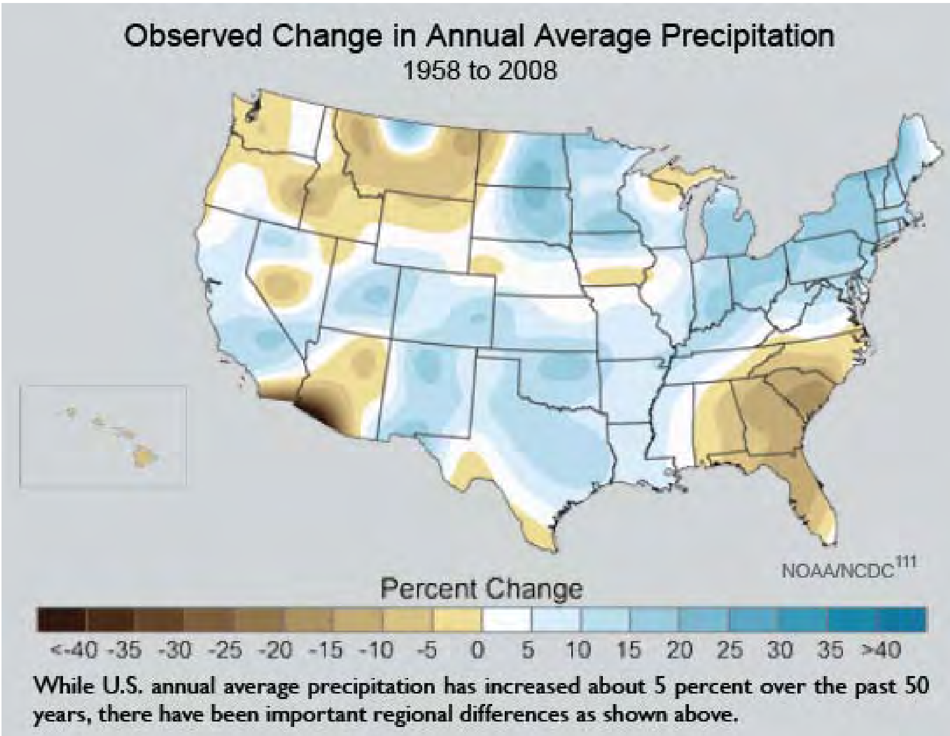
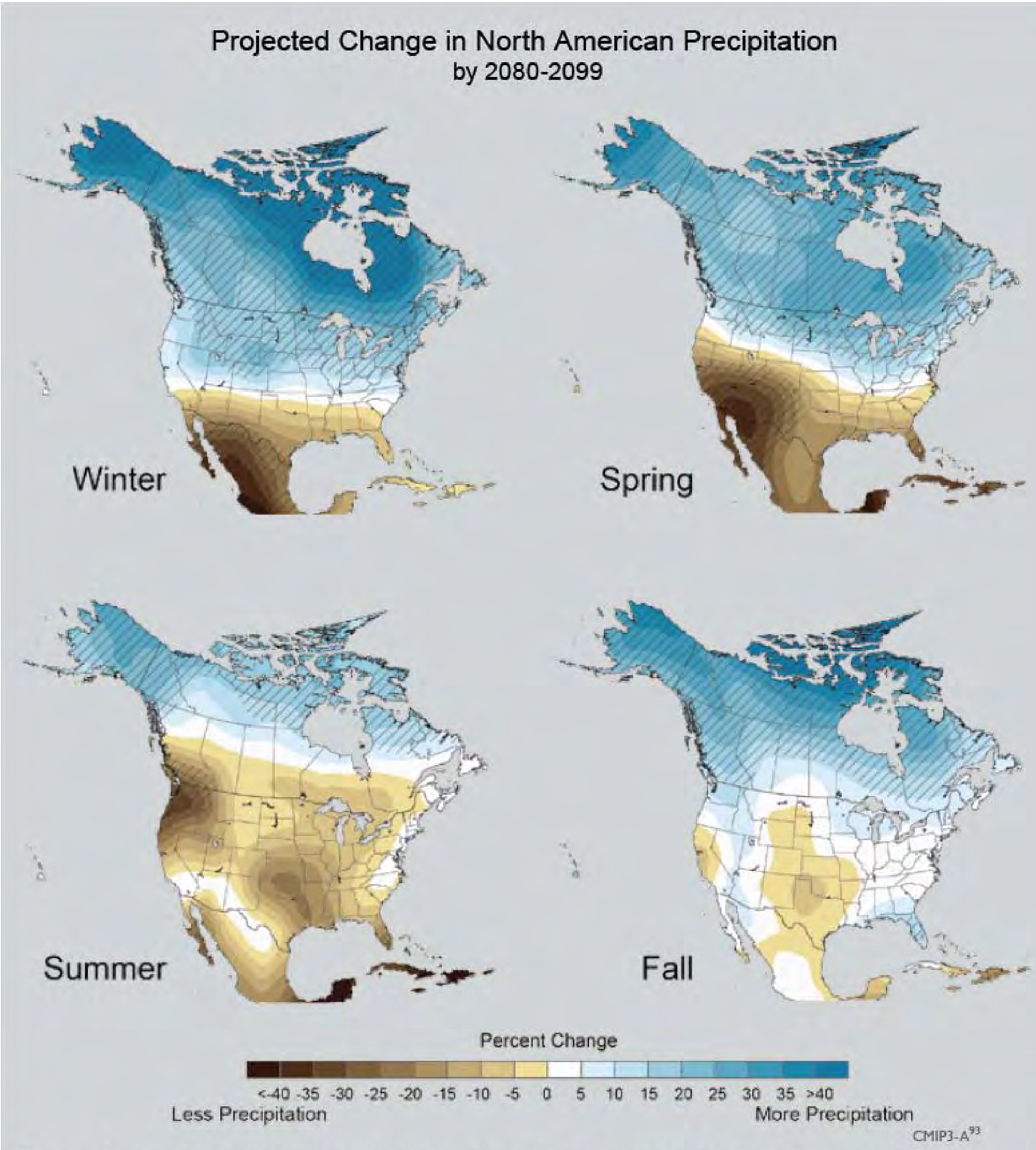
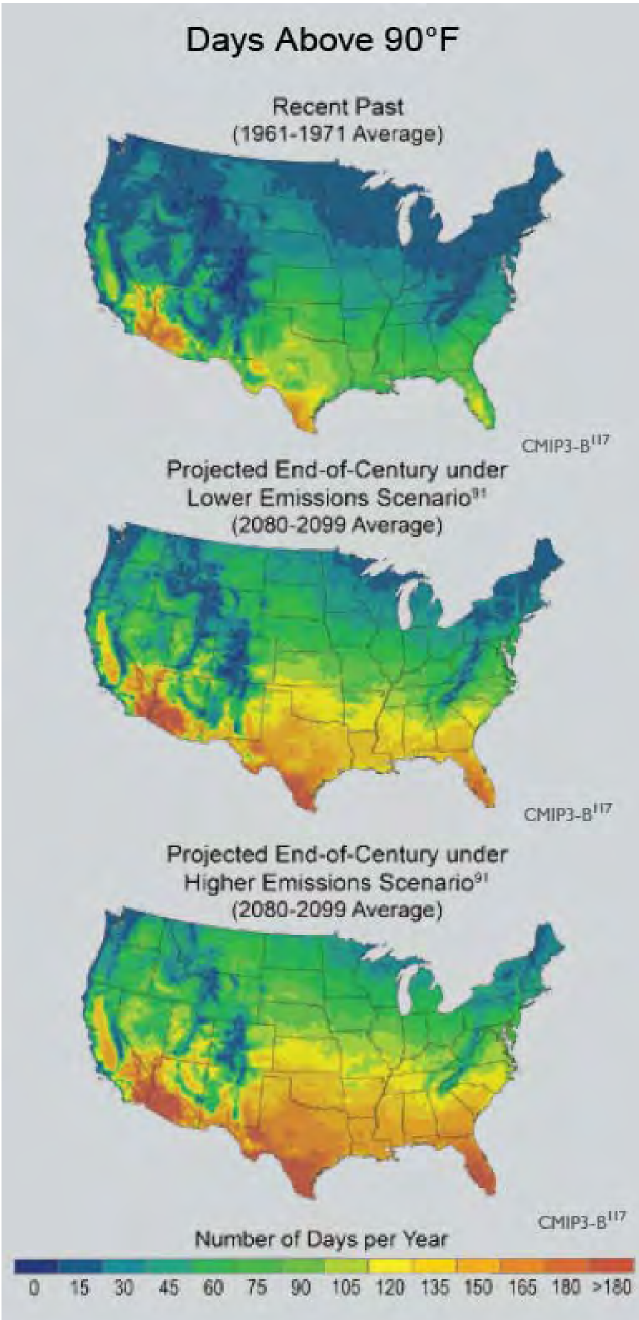

Observed Change in Annual Average Precipitation
1958 to 2008
NOAA/NCDC111
Percent Change
<-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 >40
While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.

Figure 4



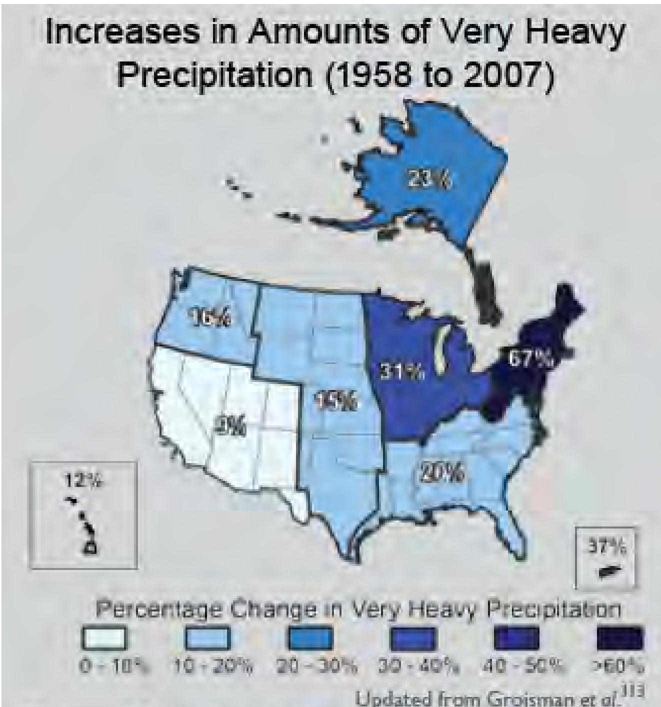
The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[91] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

Figure 5



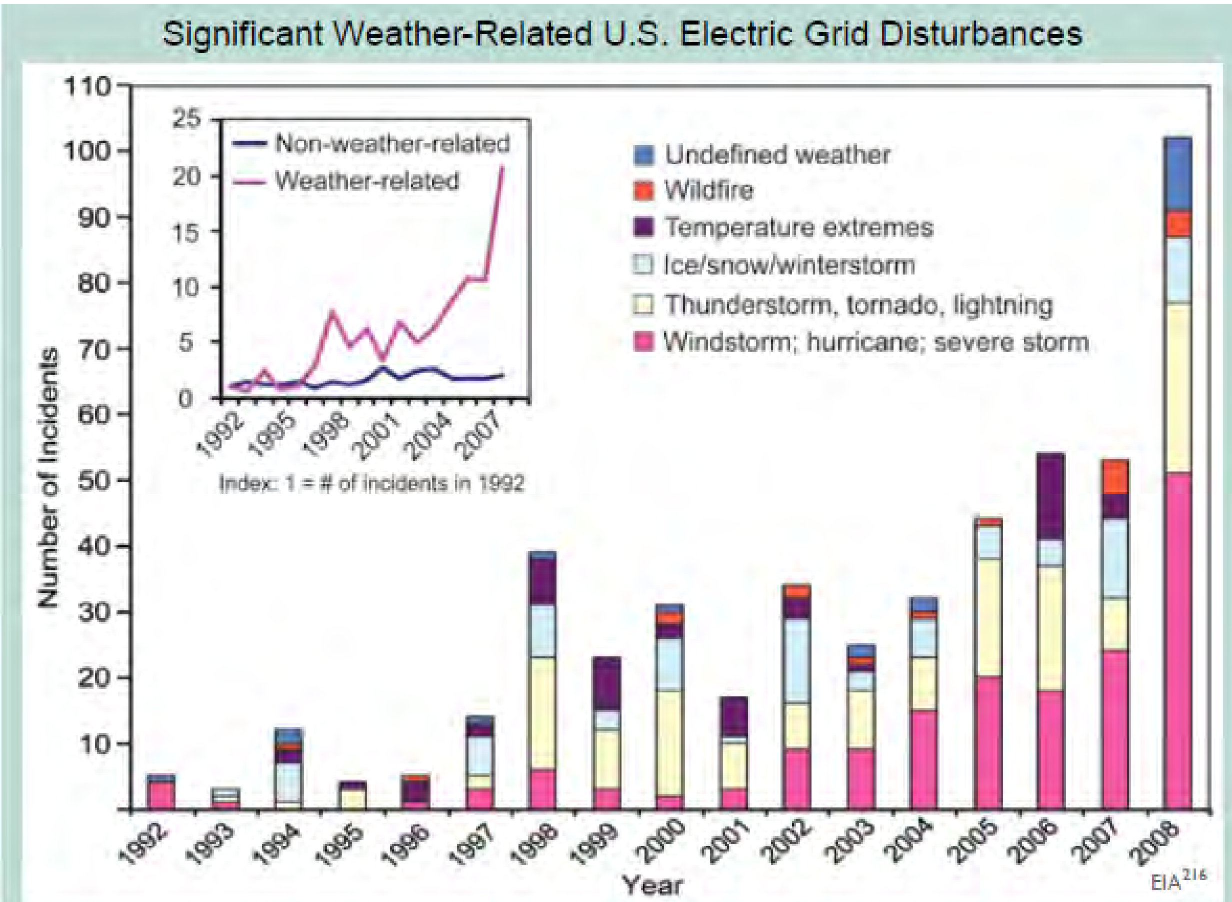
The average number of days per year when the maximum temperature exceeded 90°F from 1961-1979 (top) and the projected number of days per year above 90°F by the 2080s and 2090s for lower emissions (middle) and higher emissions (bottom).[91] Much of the southern United States is projected to have more than twice as many days per year above 90°F by the end of this century.

Figure 6



The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Figure 7



The number of incidents caused by extreme weather has increased tenfold since 1992. The portion of all events that are caused by weather-related phenomena has more than tripled from about 20 percent in the early 1990s to about 65 percent in recent years. The weather-related events are more severe, with an average of about 180,000 customers affected per event compared to about 100,000 for non-weather-related events (and 50,000 excluding the massive blackout of August 2003).[201] The data shown include disturbances that occurred on the nation's large-scale "bulk" electric transmission systems. Most outages occur in local distribution networks and are not included in the graph. Although the figure does not demonstrate a cause-effect relationship between climate change and grid disruption, it does suggest that weather and climate extremes often have important effects on grid disruptions. We do know that more frequent weather and climate extremes are likely in the future,[68] which poses unknown new risks for the electric grid.

Figure 8

The Impact of Climate Change on Indoor Environmental Quality

Climate change may affect indoor environmental quality in two fundamental ways. One is in direct response to climate change itself. For example, if climate change results in more frequent or severe hurricanes, then increases in mold, bacteria and building dampness may lead to increased indoor air quality problems (Chew 2006, Rabito 2010, Rao 2007). The second is indirect: actions taken to reduce emissions of greenhouse gases may lead to increased concentrations of indoor air contaminants. For example, significant amounts of energy used to heat, cool, dehumidify and humidify are intentionally ventilated or accidentally leaked from a building. Reducing intentional ventilation rates or air sealing an enclosure to reduce accidental infiltration reduces greenhouse gas emissions, but it also lowers a building's total ventilation rate. Lower overall ventilation rates increase the concentration of some indoor contaminants and may lead to excessively high indoor humidity levels during cold weather. The result is greater exposure to indoor air contaminants.

The indoor environmental impacts that will result from climate change or our responses to climate change are:

- Increases in indoor air contaminants due to energy conservation measures to reduce greenhouse gas emissions.
- Increases in outdoor air contaminants that affect indoor air.
- Increases in the range and population of problem organisms. The loss of electric power for extended periods of time.

<u>Energy conservation to reduce greenhouse gas emissions increases indoor environmental problems</u>

Executive summary

1. Building construction and operation is responsible for about 48 percent of U.S. greenhouse gas emissions.
2. Energy-efficient building construction and retrofit programs have been operating in the U.S. since the oil embargoes of the 1970s. Avoided energy use is the least expensive form of power.
3. The Austin Energy Green Building Program won, in 1992, one of 10 Earth Summit awards for a government environmental program at the UN Conference on Environment and Development in Rio de Janeiro. Since then a number of building programs

addressing environmental issues have been established in the government and private sectors. All of these programs recognize the importance of making building enclosures and mechanical systems energy efficient and include energy-efficiency requirements.Energy and environmentally efficient programs represent a significant and rapidly growing fraction of newly constructed, retrofitted and remodeled buildings. For example, 110,000 of the approximately 500,000 single family residences built in 2009 were part of the EPA Energy Star Homes program. The National Weatherization Assistance Program grew from weatherizing around 100,000 units per year at an allowable cost of $3,500 per unit in 2009 to 200,000 units at an allowable cost of $6,500.

4. A number of energy conservation measures are likely to result in indoor environmental quality (IEQ) problems unless they are implemented with concurrent control measures. For example:
    a. Sealing buildings four to 10 times more air tight than they were before the 1980s is a big energy saver but lowers overall ventilation rates and is likely to increase indoor air contaminant concentrations and indoor air humidity levels unless concomitant energy efficient ventilation systems are designed and installed.
    b. Heavily insulated foundation, wall and roof systems must manage liquid water intrusion, air leakage and water vapor migration better than more traditional assemblies or moisture problems will occur. Increased system analysis and quality control must be undertaken during new energy-efficient construction and energy-efficient retrofits.In single-family and low-rise multifamily residential buildings replacing atmospherically vented combustion equipment (e.g., furnaces, boilers and hot water heaters) with more than 90 percent efficient combustion or electric equipment lowers the ventilation rate in basements and crawlspaces (no more always-open chimney through the house). In some buildings, replacing this equipment changes the indoor moisture balance and results in cold weather condensation in the building enclosure.
    c. Items a, b and c occur in both new construction and existing buildings (e.g., building performance retrofits, renovations and remodeling). Additional IEQ problems are likely to be encountered when making an existing building more energy efficient. For example:
        i. Legacy hazards such as lead paint, asbestos, PCBs and banned pesticides are often found in older buildings.
        ii. Ventilation systems in older buildings may be unable to meet current ventilation codes, much less the best practice standards required when the enclosure is made air tight. These systems may be disabled, broken and unrepaired, removed and not replaced, or their design may not meet current standards.
        iii. Air sealing and adding insulation to foundations, walls and roof systems that have sub-acute rain seepage or condensation problems can easily lead to serious decay, mold growth or corrosion problems.
5. Implementing preventive measures requires a twofold effort:

a. An effective and large training effort is needed to implement existing knowledge. A large body of information on preventing and mending these problems is already part of the energy and environmentally efficient building programs. This knowledge has evolved in response to problems practitioners have faced in implementing these programs over the past three decades. Although each program incorporates some requirements intended to prevent IEQ problems:
   i. The required body of knowledge is not consistently implemented across programs. For example, most of the programs have either inadequate or no moisture control requirements. The U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) commercial and institutional programs have no requirements or credits to prevent moisture problems in their buildings. Indeed, a number of LEED labeled buildings have had significant moisture problems. Pest control is not covered in most of the programs. Ventilation and the legacy contaminants are erratically addressed, at least in residential programs.
   ii. The public and private sector energy and environmentally efficient programs are growing very rapidly. Training new workers entering this field must be effective and quickly implemented.
   iii. Outside of the energy and environmentally efficient programs, building codes are the only requirements that must be met. NOTE: A small number of design firms and contractors do not participate in one of the programs but have committed themselves to providing IEQ analyses and control measures.

b. Some IEQ issues will emerge for which interventions have not yet been sufficiently tested. (For example, adding insulation to the bottom side of roof deck with slate, metal or low-slope roofing membranes or adding insulation to the inside of brick walls in cold and mixed climates may result in moisture problems.) While methods to address these issues are being tried, they have not yet been thoroughly tested. To address these situations ongoing research to develop tested guidance is needed. In addition, with new materials and equipment arriving on the market every day, unforeseen IEQ problems are likely to occur. Programs must incorporate tracking mechanisms to identify IEQ problems as they arise and solutions as they are developed and implemented.

6. Over the past 30 years, all of the above problems have occurred in new buildings and in buildings undergoing energy-conserving retrofits. Preventing these problems is crucial. Fortunately, as these problems have occurred, many interventions have been developed to correct or prevent them. The knowledge for many of the fixes has come from the energy-efficiency programs themselves. Every energy-efficiency and environmental program incorporates indoor environmental measures that are either requirements or can be used to achieve credits; however, the treatment of the indoor environment is not consistent across programs.

Buildings are clearly the major source of greenhouse gas emissions in the U.S.

In the United States, buildings and activities related to the life cycle of buildings are among the major sources of greenhouse gas emissions. It is estimated that buildings account for around 48 percent of annual greenhouse gas emissions (Knowles 2008). Buildings contribute to climate change in a number of ways:

- Operation and maintenance: greenhouse gases released directly from the energy conversions used to heat, cool, ventilate, light and maintain buildings (36 percent annual greenhouse gas emissions).
- Production of materials used to construct buildings: greenhouse gases released during extraction, refining and manufacture of building materials (8 – 12 percent annual greenhouse gas emissions). Note: greenhouse gas emissions related to transportation of building materials are not included in this estimate.

Improved energy efficiency in new and existing buildings is the most cost-effective way to reduce current and future energy use

The most direct way to reduce greenhouse gas emissions from the building sector is to improve the energy efficiency of new and existing buildings. This involves changes in the design, construction, renovation and operation and maintenance of buildings and changes in occupant behavior (Knowles 2008).

Government and private sector programs have adopted energy conservation and the use of renewable energy sources as a way to reduce environmental impacts in general and greenhouse gas emissions in particular. Many programs that began as energy-efficiency programs have expanded their scope to include climate change issues.

There are too many programs to list them all. To give some idea of the scale of these programs, here are some examples of programs that have affected the largest number of buildings:

In 1992 ,the U.S. Environmental Protection Agency (EPA) introduced ENERGY STAR as a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. Computers and monitors were the first labeled products. In 1996, EPA partnered with the U.S. Department of Energy (DOE) for particular product categories. The Energy Star label has been extended to new homes and to commercial and industrial buildings. EPA recently launched Home Performance with ENERGY STAR, a program to help retrofit buildings. As of 2009, over 1 million U.S. homes had received the ENERGY STAR label. New housing starts have dropped by a factor of 3.7, from a high of 1.7 million single family dwellings in 2006 to around 450,000 in 2010. During that time the number of new homes receiving the ENERGY STAR label dropped from a high of around 190,000 in 2006 to 110,000 in 2009 – a factor of 1.7. Twenty percent of the 500,000 new homes constructed in 2009 were ENERGY STAR labeled homes. See Figures 9 and 10.

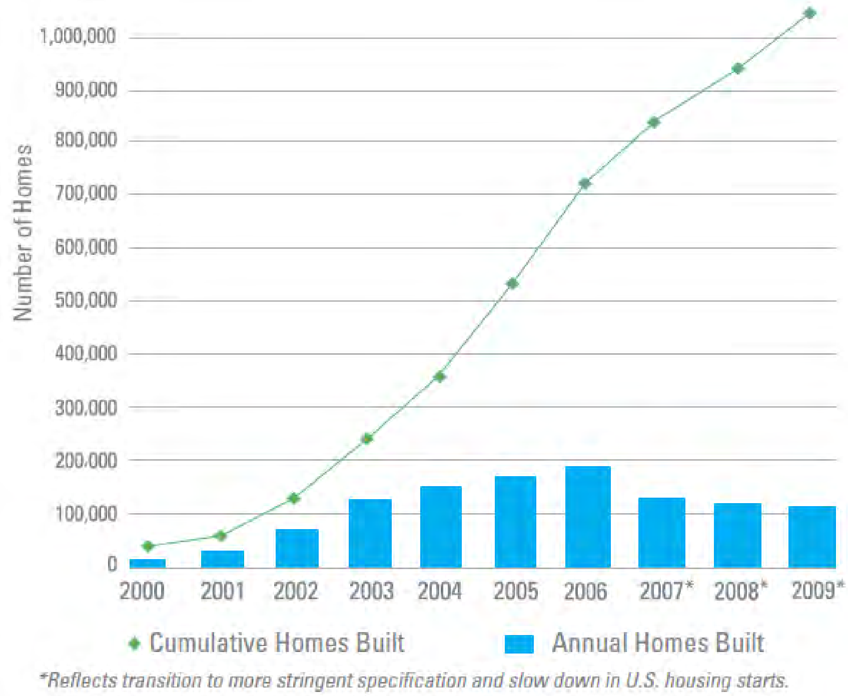


Figure 9 Number of ENERGY STAR homes built between 2000 and 2009.

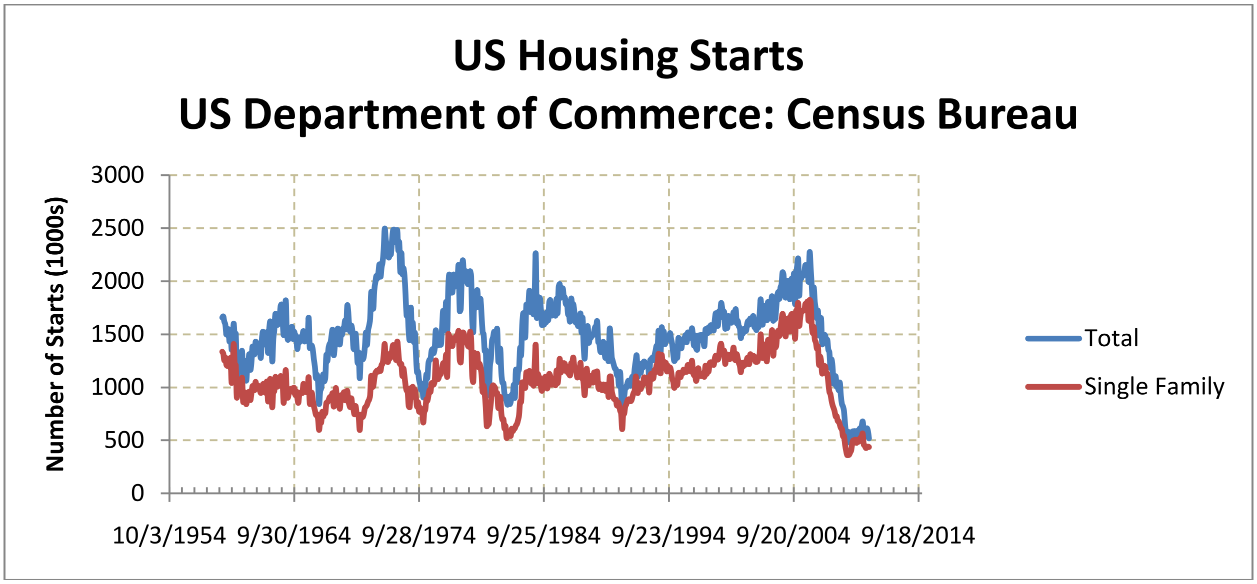


Figure 10 History of US housing starts

In 1999 EPA, DOE and the Department of Housing and Urban Development (HUD) initiated Home Performance with ENERGY STAR, a home energy performance program for existing homes. Home Performance with ENERGY STAR provides guidelines and marketing support to help state and local groups. There are programs in 29 states. The programs often are partnerships of government agencies, regional building science technical support organizations, building performance contractors and utility programs. They provide training and quality assurance for participating home performance contractors who can help owners bring their homes up to ENERGY STAR standards for new construction. A home must be tested to demonstrate performance in order to receive an ENERGY STAR label. Over 75,000 homes have been improved through the Home Performance with ENERGY STAR programs.

In 1995 the DOE launched Building America, which partnered residential developers and builders with building scientists and building product manufacturers. The primary goal was to accelerate the development and adoption of energy conservation in new residential buildings. The program included secondary goals of improved durability and lowered greenhouse gas emissions. The Building America program has produced new energy-efficient residences with good moisture management and high-quality ventilation systems. The information developed by this program has been transferred to other builders through websites, guidance documents, research monographs and seminars. By 2010 the Building America program had produced over 41,000 homes.

The National Weatherization Assistance Program (WAP) was launched in 1976 to help Americans with limited financial means respond to rapidly escalating fuel prices during the oil embargoes of the 1970s. The WAP programs weatherize existing homes. Over the past 33 years they have provided weatherization services to over 6.4 million low-income households. WAP is a subsidy-driven program. While the major funding comes from DOE, additional funding comes from a variety of sources including Low Income Home Energy Assistance Program (LIHEAP) block grants and utility programs. WAP conducts energy audits and selects appropriate energy-conserving measures that can be implemented for costs that do not exceed a dollar cap (averaged over their customer base). In 2008 WAP provided services to around 100,000 households at a cap of $3,500 per unit. In 2009 this rose to 171,000 units with a total budget of $1 billion dollars (about $421,000 from DOE funding). As the Weatherization Assistance Program Technical Assistance Center notes, “The American Recovery and Reinvestment Act (ARRA) was signed into law on February 17, 2009. This Act provides $5 billion in additional funding to the Weatherization Assistance Program over three years. With these funds, Grantees of the Weatherization Program faced great challenges to ramp up to meet the goals of the Obama administration and provide energy efficiency improvements to hundreds of thousands of low-income households” (http://www.waptac.org/WAP-Basics/Recovery-Act.aspx). As the result of additional money being provided to WAP, the target number of units weatherized for 2010 is 200,000 with a cap of $6,500 per unit.

In 2009 DOE launched Better Buildings, a major energy-conservation home retrofit grant program. Its structure is similar to that of Home Performance with ENERGY STAR in that it incorporates retrofit guidelines, (best practices, work protocols, standard work specifications and technical standards) and certification for participating contractors. It provides support for state revolving loan funds. The funding for this program comes from ARRA funds and was $452 million for 2010. As of June 2010, 35 grants have been funded.

A number of private sector programs and labels to reduce the ecological impact of new and existing buildings were developed over this same time period. Energy conservation is a critical element in all of them. Among the most widely used are the U.S. Green Building Council's LEED labeling programs. There are LEED programs that address the design and construction of new buildings, operation and maintenance of existing buildings and single family and low-rise multi-family residential buildings. Every LEED program has energy-conserving prerequisites and numerous energy-conserving measures that can provide additional points towards certification. Currently there are 6,139 LEED certified buildings worldwide (excluding LEED for Homes buildings). There are 21,143 buildings registered in the approval process. (http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx?CMSPageID=247). The LEED for Homes program has 30,555 registered projects. Of these 8,712 have been certified. (http://www.usgbc.org/ShowFile.aspx?DocumentID=2683).

Another successful private sector program is Enterprise Green Communities. This program started in 2004. By 2009 it had produced 17,500 new and renovated affordable housing units across the U.S. The buildings must comply with comprehensive energy and environmental efficiency requirements.

Many utilities have energy efficiency programs (http://www.aceee.org/sector/state-policy/utility-policies). The amount of money spent each year on utility energy efficiency programs is large, totaling $5.3 billion dollars in 2009 (http://www.cee1.org/resrc/news_items/VibrantGrowth.php3). The program types and budget vary widely by state. For example, in 2009 utilities in California spent $1 billion, Vermont $30 million and Massachusetts $138 on fairly comprehensive energy efficiency programs. Utility programs cover residential, commercial and institutional buildings.

A last, important private sector example is the U.S Energy Service Companies (ESCOs). ESCOs have proved to be resilient providers of energy-conserving measures. They deliver services primarily to commercial, government, institutional, university, and hospital buildings. The ESCO designs and installs the energy-conserving measures and receives payment from the energy savings. Satchwell I(2010) reported the 2008 aggregate annual ESCO revenue as $4.1 billion and estimated the 2011 revenues will exceed $7 billion. Historically ESCOs have focused on energy-conserving measures with very short simple paybacks (e.g., lighting, motor and HVAC replacement) in load-dominated buildings (Goldman 2005). Air sealing the enclosure of big buildings appears to be becoming more common in ESCO work. The March 2009 issue of Building Envelope News (a newsletter published by a building enclosure retrofit company) was devoted to ESCO projects (CANAM 2009).

Some energy-conservation measures will have an impact on the indoor environment

In most U.S. climates the energy used to condition intentional ventilation and accidental air leakage is a significant fraction of the overall energy use.

Actions that reduce energy used to condition the accidental outdoor air leakage through buildings include:

- Reduce the accidental leakage:
  - Air tightening the enclosure.
  - Air tightening the air distribution systems (particularly air leaks to the outside).
  - Managing indoor-outdoor air pressure differences
  - Replacing atmospherically vented combustion equipment in residential buildings with high-efficiency combustion equipment

Actions that can reduce the amount of energy used to condition the intentionally ventilated air include:

- Providing mechanical ventilation at the minimum rate allowed by code or ASHRAE 62.1 or 62.2.
- Using ASHRAE 62.1 IAQ Procedure (6.3) to provide lower ventilation rates than allowed by the Ventilation Rate Procedure (6.2).
- Pursuing development of an IAQ procedure for ASHRAE 62.2.

Reduce the accidental leakage

There are four common methods for reducing accidental air leakage in buildings:

- Air tightening the enclosure: Sealing cracks, gaps and holes in the building enclosure reduces the amount of air that accidentally leaks in or out. In most U.S. climates this saves significant amounts of energy. Sherman (2007) reports that around one-third of the energy used for heating and cooling is associated with accidental air leakage. Although there is far less measured data on accidental air leakage from commercial buildings, it is reported to be around 20 percent to 30 percent (ranging from zero to 58 percent) of the heating or cooling energy use (Emmerich 2005, Shaw 1995, Edwards 1993). In a study of several California buildings Fisk (1988) reports that accidental air leakage makes up between zero and 30 percent of the total air exchange rate. Persily (1987) reports between 31 percent and 58 percent for a three-story office building. Between 20 percent and 40 percent of the air leakage can be sealed in existing residential and commercial buildings. In new construction it is feasible to seal 90 percent of the leakage.

- Air sealing the air distribution systems: Air leaks between air handlers, supply and return air ducts and return air plenums and outdoors increase accidental air leakage through a building. If the air handler is off, they behave like any other air leak in the enclosure. When the air handler is on, they are worse because the pressure difference across the leaks is often much larger than those generated by stack and wind. Air leaks to vented space (e.g., attics, soffits, garages or crawlspaces vented to the outdoors) are similar to air leaks to the outside. Duct leakage to the outside can be significant. Cummings (1996) reports that measured duct leakage in 70 commercial buildings in Florida averaged around 80 cfm at 25 pascals per 100 ft^2 of duct surface area.

- Managing indoor-outdoor air pressure differences: This dynamic is less obvious than the first two. If airflow through the ventilation and conditioning equipment results in excessively pressurized or depressurized zones, rooms' or building cavities' indoor air may be forced out or drawn in through the building enclosure. The most common example is probably return air plenums. Any air leak in exterior walls bounding a return plenum becomes an accidental outdoor air intake when the air handler is operating. If a mechanical room is used as a mixing chamber for return and outdoor air, the room is likely to be depressurized between 10 and 30 pascals. In extreme situations it may be depressurized by as much as 90 pascals. Another example common in residential and small commercial buildings is a duct layout with supply diffusers in every room and returns in corridors. When doors to a corridor are closed, the rooms are pressurized and the corridor is depressurized. The combination of this dynamic and duct leakage to the outside can greatly increase the air exchange rate in buildings. In a study of unplanned airflow in 70 commercial buildings, eight buildings had between 2 and 10 air changes per hour when the air handlers were running (Cummings 1996). Similar results have been reported for residential buildings. A research project on 91 Florida homes found that the average air exchange rate went from 0.21 ACH with air handlers off to 0.91 ACH with air handlers on (Cummings 1989).

- Replacing atmospherically vented combustion equipment with high-efficiency combustion equipment in residential buildings: Atmospherically vented combustion equipment vents through a chimney. The chimney ventilates the equipment room. When the equipment is not running, the chimney exhausts air. When the equipment is running it ventilates at a much higher rate because of the high flue gas temperature. Measurements made by the author in the 1980s found flows of air through chimneys typically ranged from 50 cfm to 100 cfm. High-efficiency combustion equipment (e.g., condensing furnaces or boilers) do not have a chimney. They vent through plastic pipes through a side wall. The combustion gases are vented to the outside through a small fan, typically at rates in the range of 25 cfm. When the equipment is not firing, the flows are essentially zero. Some equipment is sealed combustion equipment that draws no air from the mechanical space. Heat pumps need no vents because there is no combustion. This dynamic affects single family, some low-rise multifamily buildings and small commercial buildings that are constructed using residential methods. If the equipment is located in a basement or crawlspace in a climate with a significant heating season, the ventilation through a chimney is often controlling humidity that enters through the foundation.

IEQ Impacts of reducing the accidental air leakage

- Reduced dilution of air contaminants from indoor sources.
- Changed condensation potential:
  - Higher cold weather indoor humidity (increased risk of condensation in enclosure).
  - Less airflow through the enclosure (decreased risk of heating and cooling mode condensation in enclosure, decreased risk of ice dams in snowy climates).
  - Sealing air distribution systems may increase cooling mode condensation risk (shorter air conditioning run-times).

Reducing the accidental ventilation rate is likely to increase the concentration of indoor air contaminants. Indoor humidity levels are also likely to increase. Although water vapor is not an air contaminant itself, higher indoor humidity may lead to condensation and subsequent mold growth. It also reduces the rate at which wet materials dry – materials that accidentally get wet stay wet longer. A small rain leak that dries too quickly to cause a problem may become one at higher indoor humidity levels. The risk of these two outcomes begins to increase at an indoor relative humidity of 70 percent and increases exponentially as it approaches 100 percent.

When accidental airflow rates through buildings are reduced and contaminant sources are constant, it is expected that indoor air contaminant concentrations will increase in proportion to the decrease in air leakage. However, the source terms for many contaminants found in indoor air are not constant. For a particular contaminant the concentration may go up, stay the same or go down. How an indoor contaminant concentration changes in response to a reduction in accidental air leakage depends on:

- How much the accidental air leakage has been reduced. If the expected increase is small compared to the ordinary variation of ventilation and source terms of indoor contaminants, then it is unlikely a measureable change in concentrations will occur.

- The fraction of the overall dilution air provided by mechanical ventilation and accidental air leakage. For example, nearly all ventilation in single family residences is provided by accidental air leakage. If the accidental air leakage is reduced by 50 percent, the expected impact on indoor air contaminant levels is a doubling. On the other hand, ventilation in a school classroom is intended to be primarily by intentional mechanical ventilation. A 1,000-square-foot classroom may have a mechanical ventilation rate of 500 cfm, essentially no accidental leakage when the ventilation is running because the building is pressurized by the outdoor air. Air only accidentally leaks through around 600 square feet of wall overnight. A relatively typical school wall is likely to leak 50 to 100 cfm overnight. Assuming the ventilation runs 12 hours a day, the accidental leakage is 600 to 1,200 cubic feet per day and the mechanical ventilation rate is 6,000 cubic feet per day. Completely air sealing the exterior wall will have very little impact on indoor air contaminant concentrations when the classroom is occupied.

- Whether the contaminant source term is affected by the activities that reduced accidental airflow.
    - If the contaminant source is outside of the building, reducing accidental airflow may change the source term of the contaminant. For example, if air leaks in the return side of an air handler passing through a crawlspace are drawing radon or humid air into the building, sealing the air leaks in the return ducts is likely to change the source term for radon or water vapor and lower indoor concentrations.
    - If air sealing results in higher indoor humidity levels during the summer it may increase the source term for formaldehyde.

During the oil embargoes of the 1970s, fuel prices in the U.S. rose at double digit rates. Part of the response of building owners and operators to fuel prices that were outside the budget was to air seal buildings and disable ventilation systems. Figure 11 shows plywood covering the outdoor air intake for a public school classroom. Disabling ventilation systems during this time was fairly common. This resulted in a number of indoor air quality problems in affected buildings (Daisey 2003, Brennan 1991). The same approach should be avoided in the design of energy efficient new buildings and in building energy efficient retrofits.

Figure 11 Plywood covering the outdoor air intake for a classroom. Applied during the oil embargoes of the 1970s, the classroom remained under-ventilated until the mid 1980s.

Interventions

A number of actions can be taken to prevent IEQ problems that result from air sealing buildings. They include:

- Reducing sources of indoor contaminants.
    - Building-related sources: It is often impractical to change sources in an existing building. However there are a number of legacy contaminants found in older buildings that sometimes must be addressed including lead paint, asbestos and PCBs. There is guidance for designing new buildings to minimize building related contaminant sources (ASHRAE 2009).
    - Occupant-related: very difficult.
- Providing minimum recommended ventilation rates.

- ASHRAE Standards 62.1 Ventilation for Acceptable Indoor Air Quality and ASHRAE 62.2 – 2010 Ventilation and Indoor Air Quality in Low-Rise Residential Buildings provide ventilation rate guidance by building use. Single family residences and other buildings that rely on accidental air leakage to meet minimum dilution ventilation requirements are particularly vulnerable when they are air sealed. When making houses more airtight, a decision must be made on whether or not to add ventilation systems. Air tightness testing of existing houses can be conducted to estimate whether or not fan-powered ventilation must be added because air leakage can no longer reliably provide minimum ventilation rates. Many Weatherization Assistance Programs use this method. The information can be used in two ways:
  - Air seal the house to just before the point that a fan-powered ventilation system would be needed.
  - Air seal the house past this point and install a fan-powered ventilation system. ASHRAE 62.2 – 2010 Ventilation and Indoor Air Quality in Low-Rise Residential Buildings provides a method for testing an existing house and designing a ventilation system.
  - Which approach is taken depends on whether there is a budget that can be used to provide the ventilation system.

- The 62.1 – 6.3 IAQ Procedure allows calculation of ventilation rates that will keep target indoor air contaminants below recommended levels. The IAQ procedure calculates the effects of improved source control and filtration to allow lower ventilation rates than the prescriptive ones listed in the Ventilation Rate Procedure (Johnson 2006). ASHRAE 62.2 does not have a similar IAQ procedure.

- Designing enclosures to be heavily insulated, airtight, and to manage rainwater and control condensation in heating and cooling modes (ASHRAE 2009).

- Managing indoor dewpoint/relative humidity using:

  - Water vapor source control.Ventilation when the outdoor air dew point is less than 55 degrees F.Air conditioning when weather is warm and humid. (Harriman 2006).

- Designing and maintaining buildings and landscapes to be resistant to colonization by pests (ASHRAE 2009).

- Teaching design, construction and buildings and grounds personnel how to do what we already know.

- Pursuing energy-efficient cooling strategies with good part-load dehumidification performance.

Training

An effective and large training effort is needed to implement existing knowledge. Providing the building design, construction, retrofitting and maintenance community with the best currently available information is crucial. A large body of information on preventing and correcting these problems is already part of the energy and environmentally efficient building programs. The knowledge has evolved in response to problems practitioners have faced in implementing these programs over the past three decades. Although each program incorporates some requirements intended to prevent IEQ problems:

- The body of knowledge required is not consistently implemented across programs. For example, most of the programs have either inadequate or no moisture control requirements. The LEED commercial and institutional programs have no requirements or credits to effectively prevent moisture problems in their buildings. Ventilation and the legacy contaminants are erratically addressed, at least in the residential programs.

- Public and private sector energy and environmentally efficient programs are growing at a very rapid rate. Training the new workers entering this field must be effective and quickly implemented.

- Outside of the energy and environmentally efficient programs, building codes are the only requirements that must be met. Inclusion of IEQ issues in most remodeling and renovation work depends entirely on the knowledge and skill of the designers, contractors, building owners and operators. Asmall number of design firms and contractors do not participate in one of the programs but have committed themselves to providing IEQ analysis and control measures.

Comprehensive coverage of IEQ issues is available for the design and construction of new residential and commercial buildings. For example, in the residential new construction arena:

- New residential guidance
  - EPA has developed the ENERGY STAR Indoor Air Package (IAP). The ENERGY STAR baseline program already has a number of requirements that contribute to indoor environmental quality. The IAP program adds to the baseline ENERGY STAR requirements to address a broader range of IEQ issues. The IAP includes requirements for moisture control, pest management, combustion safety, ventilation, emissions from building materials and radon control (EPA).

  - The National Center for Healthy Housing has developed significant training programs for a variety of stakeholders: designers, builders, owners, code inspectors and public health workers (NCHH). The training covers new and existing buildings as well as multifamily buildings. It includes ventilation, moisture control, dust control, integrated pest management, material emissions and managing air pressure relationships.

  - The American Lung Association developed the ALA Healthy House program. The guidance is comprehensive but available only to those who participate in the program (EPA 2009).

- The *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* was developed by ASHRAE, The American Institute of Architects, Building Owners and Managers Association International, Sheet Metal and Air Conditioning Contractors Association, EPA and the U.S. Green Building Council. The guide consists of two parts: Part 1 - Summary Guidance, a 176 page book and Part 2 – a CD filled with detailed information for each strategy in Part 1.

Comprehensive guidance for IEQ issues during the design and implementation of energy conserving retrofits is not yet available for residential or commercial buildings.

IEQ issues in existing residential building retrofit and renovation is partially covered by many of the programs. There is particularly strong coverage for combustion safety issues by the WAP and programs that have evolved from WAP work. Two emerging programs at the federal level are addressing IEQ issues during retrofit work in a far more comprehensive way.

- EPA is developing voluntary Healthy Indoor Air Protocols for Home Energy Upgrades. The draft protocols were available online for public review until December 9, 2010. The draft protocols are more comprehensive than any of the existing home programs. They cover assessment and response to specific indoor environmental contaminants plus ventilation and worker safety related to:

  - Asbestos
  - Environmental tobacco smoke (multifamily buildings)
  - Garage air pollutants
  - Lead
  - Moisture
  - Ozone
  - Pests
  - Radon
  - Other emerging issues
  - Combustion safety
  - Exhaust ventilation for localized sources

  - Whole house ventilation
  - Home safety
  - Work safety

- DOE has developed Workforce Guidelines for Home Energy Upgrades. The DOE guidelines are organized into eight sections. IEQ and health and safety issues are covered within each section along with guidance for specific energy-conserving measures. Because it covers work practices for achieving energy savings, the DOE document is far longer. The sections are:

  - Home performance assessment
  - Combustion appliances
  - Ventilation
  - Air sealing
  - Heating and cooling
  - Insulation
  - Crawlspaces and basements
  - Baseload

EPA and DOE have worked extensively together in the parallel development of both documents. From the draft Workforce Guidelines:

"The U.S. Department of Energy (DOE) Weatherization Assistance Program and the broader residential energy efficiency retrofit industry are experiencing significant growth as a result of investments made through the American Recovery and Reinvestment Act and increased societal awareness of the economic, employment, and health benefits of reducing home energy consumption.

In support of this expansion, DOE and the U.S. Environmental Protection Agency (EPA) are developing two keystone documents pertaining to quality and health considerations in residential energy efficiency retrofits. These documents are being developed in conjunction with one another and are complementary and mutually supportive. Both are intended to provide a set of voluntary measures that the Weatherization Assistance Program and other energy efficiency retrofit efforts can adopt to increase the quality of the retrofit work performed while maintaining or improving the health and safety of the occupant.
Together, the two documents will:

- Provide a robust and practical set of resources for retrofit contractors, trainers, and program administrators.

- Help improve the quality of the work performed in this expanding industry.

- Promote occupant health and safety.

- Drive consumer demand for energy efficiency retrofit services.

DOE and the EPA have collaborated closely throughout the production of these two documents. In particular, the two agencies have strived [sic] to make certain that the EPA minimum actions are fundamentally integrated appropriately into the DOE *Standard Work Specifications for Energy Efficiency Retrofits*, which form the bulk of the guidelines, so that retrofit workers following the DOE document will inherently achieve the EPA minimum recommendations. Any inconsistencies will be reconciled during the forthcoming public comment periods for both of these documents. Additionally, both DOE and the EPA fully support the retrofit industry going above and beyond the minimum actions by adopting the EPA-recommended expanded actions, but both agencies also understand that financial or programmatic constrains may impede this in certain cases."

These two documents provide comprehensive guidance that, if implemented in home energy performance retrofits, will have a positive impact on indoor environments. Significant training resources are in place for home energy retrofits in both the public and private sector.

The WAP grantees and subgrantees use professionally trained staff and contractors. Historically they have made their own decisions on how training is provided. While this creates some regional variability across the country, protocols for building assessment, weatherization measures and quality assurance procedures have evolved into a fairly consistent set of industry practices (WAP 2009). Training may be provided by independent weatherization trainers, in-house technical trainers and local or regional weatherization training centers. Typically training is provided by a mixture of these three. In 2009 90 percent of states used state agency staff for training, 75 percent used local agency peers for training and 70 percent used independent trainers. There are 12 weatherization training centers in 11 states. Grantees also make their own decisions about certification. Some require certification by a national organization (e.g., Residential Energy Services Network [RESNET], Building Performance Institute [BPI]). Some provide their own certification, while some do not require certification (17 states).

Many of the training facilities for the WAP also provide training to private sector building performance contractors. The 12 weatherization training centers provide training that reaches beyond the WAP community. The Building Performance Institute provides training through a network of training affiliate organizations, individual certifications, company accreditation and quality assurance programs. RESNET develops standards and certification for Home Energy Raters.

DOE has developed a plan to provide additional training for workers new to the weatherization field (WAP 2009). That EPA and DOE are cooperatively developing home energy retrofit and IEQ protocols is encouraging. It should noted, however, that the energy-efficiency sector is growing in many areas outside the government and private sector programs and is expected to grow from around 110,000 person years of employment (PYE) to between 200,000 and 380,000 PYE by 2020 (Goldman 2010). See Figures 12 and 13 for high growth and low growth scenarios.

A large-scale training program that includes public and private sector programs and the numerous building remodelers and contractors who are not associated with any of the existing programs will require a well-coordinated plan.

Some IEQ issues will emerge for which interventions have not yet been sufficiently tested. (For example, adding insulation to the bottom side of roof deck with slate, metal or low slope roofing membranes or adding insulation to the inside of brick walls in cold and mixed climates may result in moisture problems.) While methods are being tried for these conditions, they have not yet been thoroughly tested. To address these situations ongoing research efforts to develop tested guidance are needed. In addition, with new materials and equipment arriving on the market every day, unforeseen IEQ problems are likely to occur. Programs must incorporate tracking mechanisms to identify IEQ problems as they arise and solutions as they are developed and implemented.

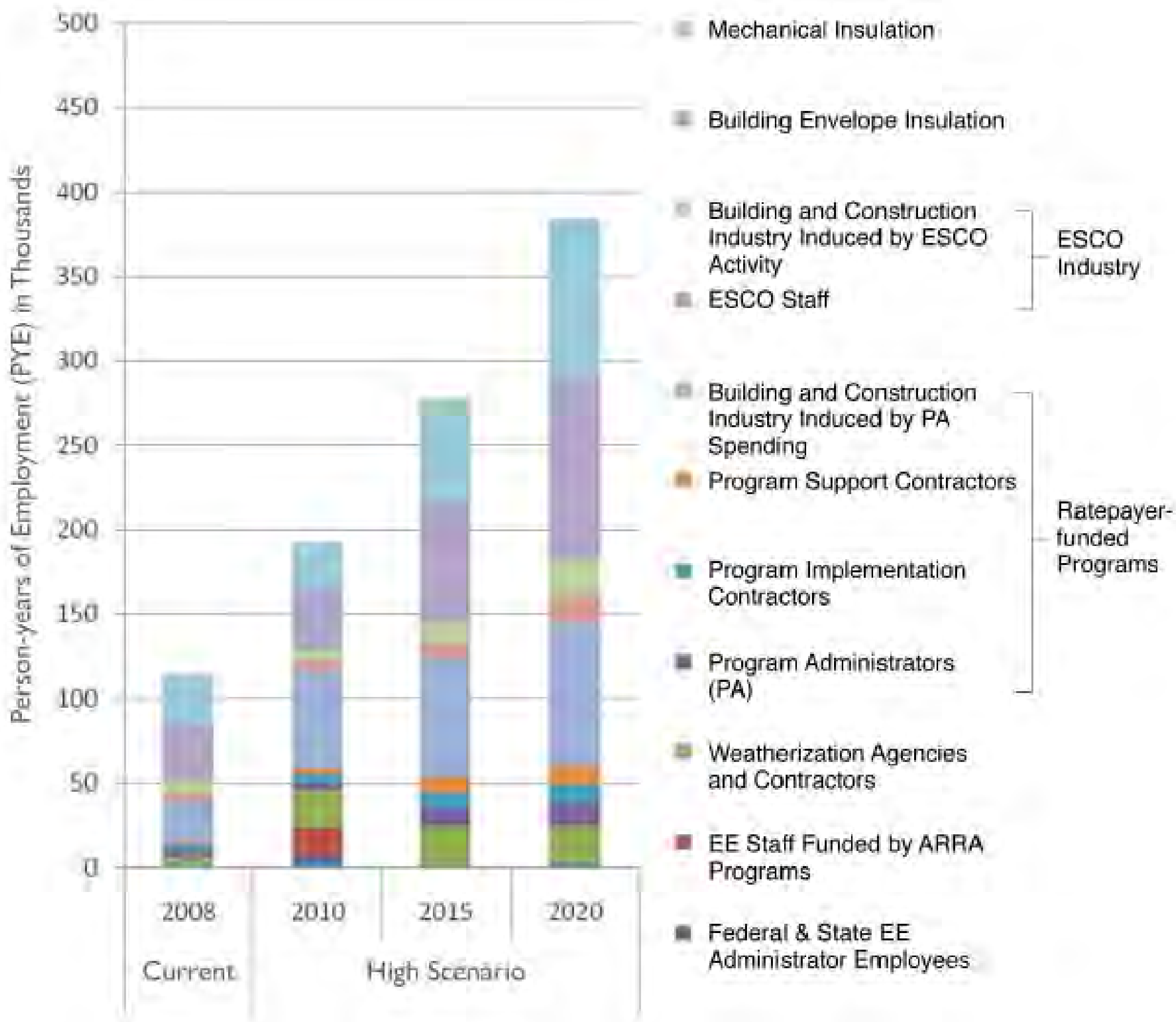


Figure 12 Low-growth scenario for jobs in the energy-efficiency services sector.

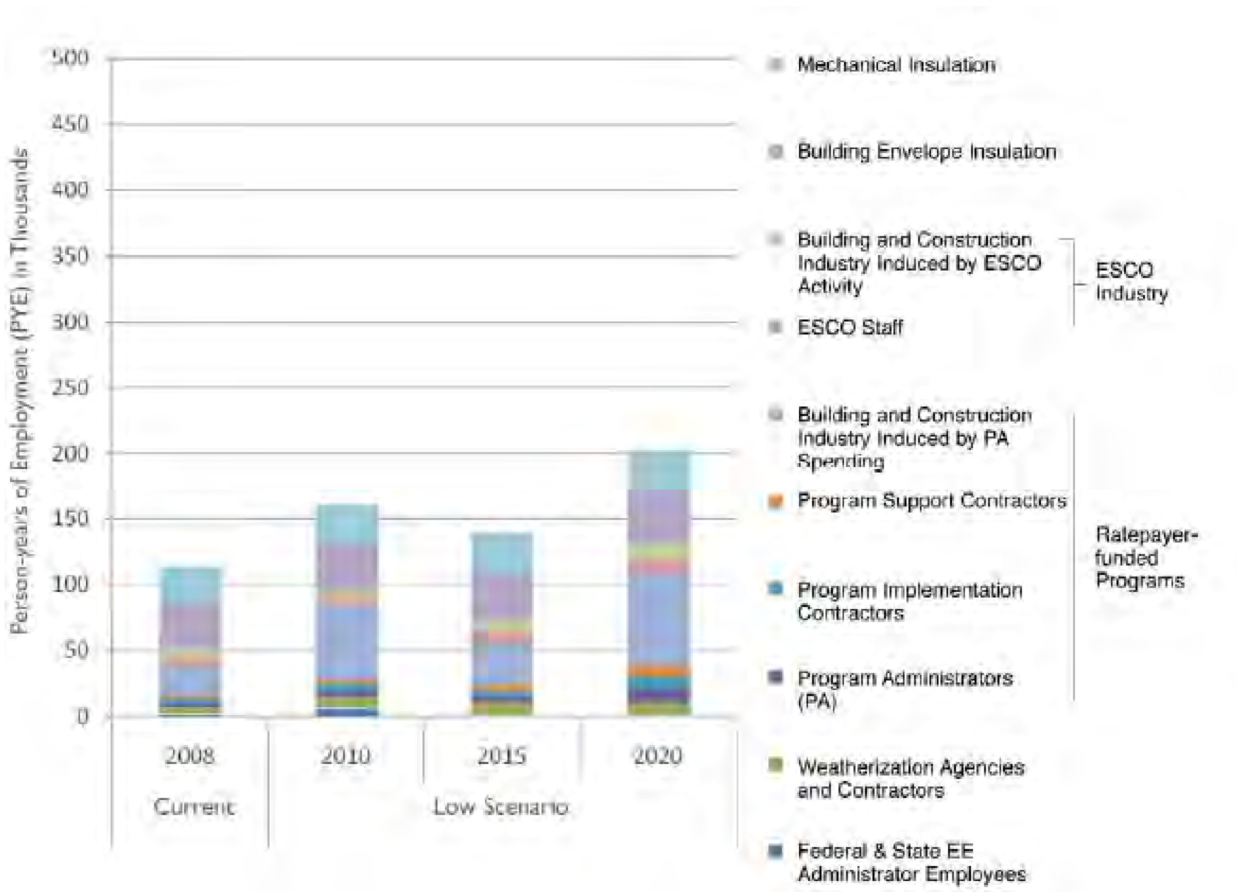


Figure 13 Low growth scenario for jobs in the energy efficiency services sector.

Increase in outdoor air contaminants that impact indoor air

Increased ozone: The outdoor air contaminant most likely to increase as the climate becomes warmer and dryer is ozone. Outdoor air ozone is largely the result of chemical reactions between NOx and VOCs in the presence of heat and sunlight. Climatic changes that increase persistent high pressures, warm temperatures, clear skies and poor atmospheric mixing favor net ozone production increases. Different climatic models of ozone production predict net increases in ozone production for some regions of the U.S. and net decreases for others. All the models predict increases for some portions of the U.S. The models disagree about the effect on some regions, but agree on net increases for others, such as the mid-Atlantic region. On average, increases in summertime ambient ozone levels in the U.S. are expected to be in the 2 – 8 ppb range (Weaver 2009).

Outdoor air ozone becomes an indoor air quality problem when it migrates into buildings. Ozone itself is an air contaminant with potential health endpoints. It also reacts with compounds found in the indoor environment to produce new compounds, some of which have associated health risks. For example, terpenes, relatively non-toxic compounds that are frequently found in cleaning products, react readily with ozone to produce formaldehyde, OH radicals and fine particle matter (Weschler 2000, Nazarof 2006).

Increased wildfire-related issues: An increased frequency and duration of droughts and earlier snow melt in some areas are expected to increase the frequency and extent of wildfires (CCSP 2009). This is expected to affect buildings in two ways.

Wildfires are a significant source of fine particulate matter (PM2.5) in the outdoor air (Sapkota 2005). Indoor PM2.5 is often dominated by outdoor PM2.5. Research projects on particle penetration from outdoors to indoors repeatedly find high penetration factors (Long 2001), (Hovorka 2004), (Meng 2005). The overall impact of climate change on PM2.5 is not clear.

Although flying embers are not an air contaminant, they do pose significant fire risk to buildings. Roof and attic vents and overhangs intended to provide moisture control in wood-frame buildings cause buildings in wildfire areas to be more vulnerable to fire caused by flying embers even at some distance from a wildfire (Quarles 2004). As wildfires become more frequent in areas that do not currently experience wildfire risk, existing buildings with these details are more likely to burn when exposed to airborne embers. These buildings are likely to be retrofitted by closing vents to attics and crawlspaces and by reducing overhangs. New buildings will be designed with fire-resistant features, including unvented attics and crawlspaces. Alternate moisture control methods will need to be implemented in both retrofit and new construction or moisture problems will be more likely to occur.

Increased pollen loads: Warmer temperatures and increasing carbon dioxide increase plant growth in general, and evidence shows increases in pollen production. This applies to allergenic species as well as to more benign plants. Studies have found evidence that ragweed pollen production doubled as carbon dioxide levels rose from levels in 1900 (280 ppm) to the current level of around 370 ppm (in rural areas). Production of ragweed pollen can be expected to double again as carbon dioxide in the atmosphere rises from 370 ppm to 600 ppm. Climate warming also extends the pollen-producing season for ragweed and other allergenic species (CCSP 2009, Ziska 2003). Most whole pollen grains that get into buildings are tracked in by people or pets or float in through open windows or doors. Antigens may remain on small particles left by degrading pollen and be transported into buildings by airflow as well as by being tracked in.

Interventions

Hazards that originate outside buildings are handled by reducing the source or by excluding them from the building. Control methods for ozone include:

- Reducing the precursors to ozone production in outdoor air (e.g. NOx and VOCs). California has pioneered this approach.

- Reducing indoor air compounds that react with ozone to produce other indoor air contaminants (e.g., screen cleaning products to avoid terpenes).

- Reducing ozone entry into buildings by air sealing them and providing filtered mechanical ventilation. If air leakage is reduced enough the ventilating air could be used to slightly pressurize the building. For example, if a residence were sealed to the point where 50 cfm of outdoor air pressurized it by 4 pascals, entry through air leakage would be greatly reduced. NOTE: this would be a very well-sealed house, around 260 cfm at 50 pascals. In climates with significant cooling or heating loads, air sealing to this level has the additional benefit of reducing energy used to condition the building, thus reducing greenhouse gas emissions. Activated carbon filtration is reported in the scientific literature as a potentially practical method for removing ozone from ventilating air in commercial buildings (Shields 1999, Gundel 2002). It is possible this technology can be applied to residential buildings and ventilation systems. A number of residential ventilation equipment manufacturers offer carbon filtration options. None offer experimental data on the removal of ozone from indoor or ventilating air.

- Sealing and slightly pressurizing a building with filtered outdoor air t can be applied to PM2.5 as well as to ozone. A media filter or electronic filter would be used rather than activated carbon. Media filters would also be effective at removing pollen grains or smaller allergenic particles from degrading pollen. Protecting charcoal filters from fine particulate matter should increase the useful life of charcoal filters.

- Providing effective track-off systems at building entryways to reduce tracked-in pollen. Track-off systems consist of three parts – a stiff bristle or grate section that scrapes dirt from shoes and has the capacity to store them, a carpet portion that dries feet and collects particles that are small enough to cling to shoes after the scraper section and a hard surface floor that is easy to damp mop.

- Air sealing attic or crawlspace vents in existing buildings or eliminating them in new designs will make buildings more resistant to fire caused by embers, but they must be accompanied by alternate condensation control measures. For example, if crawlspace vents are to be eliminated, rainwater and humidity must be kept out of the crawlspace. Rainwater must be drained away from the crawlspace and kept from wicking through foundations to moisture-sensitive materials. A low vapor-permeability ground cover must prevent water vapor from entering from earthen floors. The crawlspace walls must be air sealed to prevent infiltrating air from carrying humidity into the crawlspace when the outdoor air dew point is greater than the earth temperature. If the crawlspace walls are insulated to meet minimum heat loss requirements, then insulating materials that manage both water vapor migration and heat flow to avoid condensation in both heating and cooling season are necessary. If attic vents are to be eliminated, condensation on the roof sheathing during cold weather must be prevented and in snow country the formation of ice dams must be prevented. Warm, humid indoor air must be kept from reaching the bottom side of the roof sheathing. A combination of materials must be used that provide a continuous air barrier to keep warm humid air indoor air from reaching the bottom of the roof sheathing and provide at least the minimum required insulation and water vapor control.

Problem organisms increase population and expand range

Increasing temperatures and wetter or drier climates will favor increased populations for species that compete better in the changing climate. Species that currently have a minor role in some areas may thrive in warmer and wetter or warmer and drier conditions. Species adapted for warmer climates will extend their range further north into new territory. Impacts that result from organisms flourishing or expanding their range include:

- Organisms that lead to the premature failure of buildings (e.g., termites) may expand their range.
- Organisms that contribute to the onset or aggravation of disease or affect IAQ directly (e.g., rodents, mosquitoes, dust mites and roaches).
- Increased pesticide use in and around buildings is a likely response to both situations.

Termites: The risk of termite infestation in North America is shown on the map in Figure 14 (ICC 2009). While dozens of termite species are active in North America, widespread risk to buildings is dominated by subterranean termites (family Rhinotermitidae). Some species have fairly wide distribution, tolerating a wide range of seasonal temperatures and moisture availability (e.g., the Eastern and Western subterranean termites [*Reticulitermes flavipes* and *Hesperus]*). Others have adapted to warmer and drier climates (e.g., desert subterranean termite [*Heterotermes aureus]*) or warmer and wetter climates (e.g., Formosan subterranean termite *[Coptotermes formosanus]).*

Historically, termite range has been bounded by the 50° F annual mean isotherm north and south of the equator (Ebeling 1978). Termite activity north of this limit is reported to be confined to the warmer microclimates produced in soils surrounding and beneath buildings (Ebeling 1978). Researchers believe that termites migrate deeper into the soil in response to cold weather where food resources become increasingly scarce. Termite colonies in the northern states and southern Canada do not disperse by aerial flights of winged alates as they do in the southern states (Ebeling 1978, Peterson 2010). This limits expansion of termite colonies at the northern end of the range to tunneling and transport in wooden materials. As the climate warms and frost does not reach as deeply into the earth, the termite range is likely to move further north, and termite populations in the current northern range are likely to increase. Figure 15 shows the locations of termite activity in 2005 (National Termite Survey). The northern range is dominated by the Eastern and Western subterranean termites (*Reticulitermes flavipes* and *Hesperus).* The temperature below which *R. flavipes* cannot function – the Lower Critical Thermal limit (CTMin) – is between 36°F and 39°F (Hu 2004). Overlaid on this map are the 45°F and 50°F annual mean isotherms. This gives a rough idea of the area to which termite activity might extend if temperature increases by 5°F. Termite survival overwinter is likely to be more dependent on the temperature of the coldest month rather than the annual mean. Termite activity is limited by soil moisture in the American Southwest and parts of the Great Plains (Haverty

1976). Shifting precipitation trends are likely to increase termite populations and favor different species in Colorado, Utah and parts of the Midwest.

The Formosan *(Coptotermes formosanus)* termite is of particular interest in regard to potential expansion for three reasons:

- They damage buildings at a much higher rate than other species found in the U.S. because of their large colony size and voracity (Hu 2004).

- They are currently confined to a few Gulf Coast states and Hawaii (See Figure 14). NOTE: Several species of termite active in Hawaii are not found in any other state.

- The limits of their northern range have not yet been established. While they have expanded their range significantly since their first discovery in Lake Charles, La., in 1966, it is unlikely they have reached the northern most thermal limit. The CTMin for *C. formosanus* is between 45°F and 50°F. The thermal northern limit for general success is likely to be further north than the current Gulf Coast states. Active quarantine programs by states that currently have infestations are likely to have slowed the expansion north.

Interventions

Termite incursions into new territories and increased populations in areas where termites are a light or moderate risk are likely to be met by increased use of current termite control measures. Termite control in buildings is a combination of three tactics:

- Prevention
    - Construction details that are intended to prevent termite infestations.
        - Maintain at least a minimum distance between grade and the top of foundations.
        - Use construction materials that are either naturally termite resistant (e.g., stone, concrete, Atlantic white cedar, teak) or products treated with termiticide or feeding deterrents (e.g., lumber and foam insulation treated with borates, quaternary copper compounds).
        - Provide physical barriers such as:
            - Stainless steel mesh barriers at foundation superstructure intersection and penetrations through the foundation.
        - Basaltic sand covering crawlspace floors. Use effective moisture control details (above-grade infestations require a moisture source in the building).
        - Clean all wooden and paper materials from the construction site – do not bury them or leave them in crawlspaces.

    - Soil pesticide barriers - application of pesticides to form a chemical barrier in soils surrounding building foundations.

- Regular termite inspections
    - Construction details that make inspection for termites easy.
    - Use of bait/monitoring stations to identify termite activity in the soil near buildings.
- Response to infestations
    - Reapplication of soil pesticide barrier.
    - Tenting and fogging entire buildings.
    - Application of pesticides directly to colonies.
    - Replacing bait in monitoring stations with insect growth regulator.
    - Applying above-grade bait/monitoring/insect growth regulator stations. Applying heat and microwave treatments.
    - Physically remove colonies and damaged material.
    - Identifying and repairing water sources.

In areas of the U.S. with heavy and moderate termite risk, applying pesticide barriers to the soil surrounding the foundation is a common preventive measure. Pesticides may be reapplied in response to infestations. Reapplication has become more common because the newer generations of termiticides have much shorter half-lives in the soil – e.g., 2 – 9 months for chlorpyrifos, imidacloprid and bifenthrin (Mulrooney 2006) than older generations – e.g. ,4 years for chlordane (http://extoxnet.orst.edu/pips/chlordan.htm).

The use of pesticide barriers in new regions of the U.S. will lead to increased public exposure to termiticides. Studies of pesticide exposure routes and tracked-in contaminants have repeatedly found termiticides in indoor dust and indoor air and documented consequent exposure through inhalation, dermal and secondary ingestion (Pisaniello 1993, Colt 1998, Colt 2004, Roberts 2004, EPA 2007).

There is also evidence that soil pesticide barriers currently in use are not as effective as they once were. Su (2009) reports that because of risk to humans and the general environment chlordane use was terminated during the 1980s. At that time the pest control industry switched to alternate liquid pesticides that are shorter lived and more expensive than chlordane. Once the shorter lived pesticides degrade, the soil pesticide barrier can be renewed only by drill and inject methods which are not as effective as preconstruction soil spraying. Of the newer termiticides, those that depend on repellency lose effectiveness more quickly than those that are undetectable by termites (Ogg 2006).

Tenting and fogging entire buildings also has the opportunity to expose the general population to pesticides. In addition at least one termite and rodent control fogging agent is a potent greenhouse gas. Sulfuryl flouuride is estimated to have between 120 and 7,600 times the global warming potential as carbon dioxide. Two thousand to three thousand tons are released into the atmosphere each year (Andersen 2009). This provides a feedback mechanism in which one of the effects of climate change leads to greater release of the greenhouse gases that cause climate change.

Interventions

Alternatives to pesticide intensive treatments: Alternatives to pesticide soil barriers and fogging must work with other prevention, inspection and infestation response measures. Alternatives reported to provide sufficient protection include:

- Baiting/monitoring station combined insect growth regulators (e.g., slow-acting chitin synthesis inhibitors or juvenoids) (Verma 2009, Yates 1999, Su 1998).
- Use of naturally resistant or treated building materials (Yates 1999).
- Mixed graded sand barriers (Verma 2009, Yates 1999, Su 1998).
- Stainless steel mesh barriers (Verma 2009, Yates 1999, Su 1998).
- Above-ground baiting/monitoring stations (Verma 2009, Yates 1999, Su 1998).
- Heat and microwave treatments (Verma 2009).
- Details to facilitate termite inspection.

Of these methods, the use of treated wood and foam insulation materials and the use of bait/monitoring stations combined with insect growth regulators have gained significant acceptance in the marketplace. The purpose of integrated pest management is to lower the carrying capacity of a building in regard to specific pest species. This is accomplished by intervening in the ability of a species to enter a building and find enough food, water and shelter to support and successful colony. Pesticide control alone is unlikely to be successful. The EPA/ASHRAE Indoor Air Design Guide Parts I and II contain guidance for designing buildings to be resistant to colonization by pest species (ASHRAE 2009). The guide contains some specific suggestions for termite control, including the use of stainless steel mesh and graded sand barriers to exclude termites from buildings, termite-resistant wood materials treated with borate solutions, inspection and judicious use of non-repellent pesticides or bait/monitoring/insect growth inhibitor baits.

Historically, it has proven difficult for integrated approaches that are less dependent on pesticide application to gain acceptance (Yates 1999, Su 1998, Ogg 2006). Yates III (1999) and Su (1998) report that barriers to implementation include poorly informed home buyers, lenders, contractors and architects, requirements for soil pesticide application certificates and fear of loss of livelihood on the part of pest control contractors.

Energy conservation in buildings is a crucial part of the response to climate change. Building foundations are a significant source of heat loss during cold weather and therefore sealing and insulating them is a common energy-conserving measure in both new and retrofit work. In the highest risk termite areas there are prohibitions on the use of foam board insulation to cover foundation walls or be placed beneath concrete floor slabs. Foam board on the exterior of the foundation interferes with the application of soil pesticide treatments. Foam board on either the interior or exterior of a foundation makes it difficult to inspect foundations for signs of termite infestation (e.g., mud tubes) (Ogg 2006). Above-grade inspection strips must be left open for several inches below the mud sill so inspections can be made for the mud tubes termites use to conserve moisture as they travel from the nest in the soil to the wooden portion of a building. Because concrete has very poor insulating value, the area where the strip is required is also the area of greatest heat loss through the foundation. The best compromise between termite risk and energy conservation in these areas is to minimize the amount of foundation left uninsulated (EPA 2009). The author hypothesizes that there is a potential advantage to insulating foundations in cold climates. Insulating foundations will cause the surrounding soil to become cooler during the winter. This may make it more difficult for termites to overwinter successfully, or successfully enough to produce alates. While it has been feared that this may increase the risk of freeze-thaw problems, this fear not been realized in buildings with heavily insulated foundations in cold climates (Straube 2010).

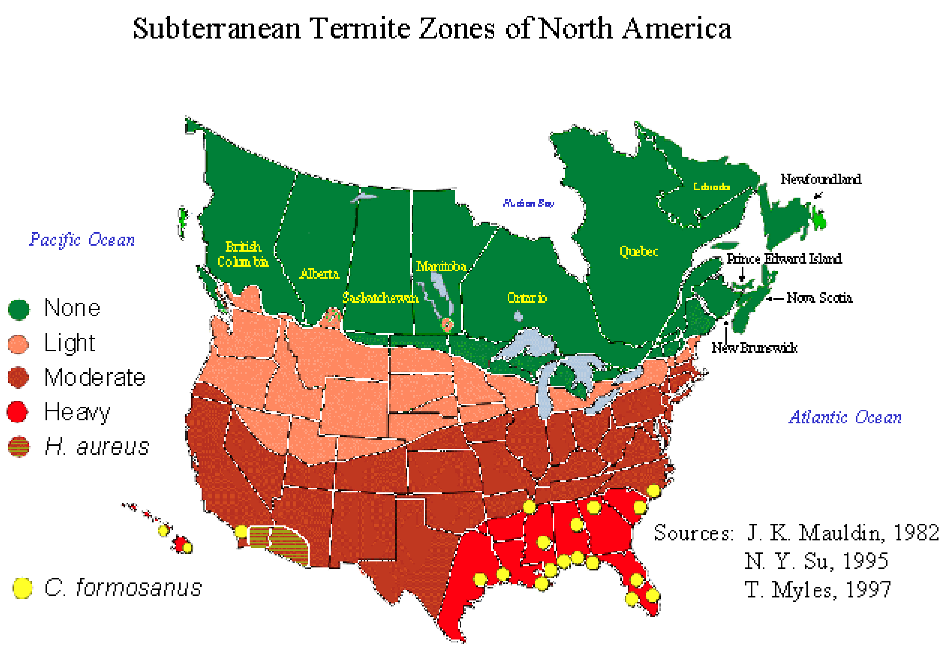


Figure 14 Termite infestation risk map.

Figure 15 Location of termite infestations reported to the National Termite Survey (National Termite Survey 2005)

References

(ALA) The American Lung Association

(Andersen 2009) M. P. Sulbaek Andersen, Atmospheric Chemistry of Sulfuryl Fluoride: Reaction with OH Radicals, Cl Atoms and O_3, Atmospheric Lifetime, IR Spectrum, and Global Warming Potential, Environmental Science and Technology, 2009, 43, 1067-1070

(ASHRAE 2009) American Society of Heating Refrigerating and Air-conditioning Engineers, *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning*, ASHRAE (2009)

(ASHRAE 2010a) American Society of Heating Refrigerating and Air-conditioning Engineers, *ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality* , ASHRAE, 2010

(ASHRAE 2010b) American Society of Heating Refrigerating and Air-conditioning Engineers, *ASHRAE 62.2 – 2010 Ventilation and Indoor Air Quality in Low-Rise Residential Building*, ASHRAE, 2010

(Brennan 1991) Brennan, T., Clarkin, M., Turner, W., Fisher, G. and Thompson, R. (1991) “School buildings with air exchange rates that do not meet minimum professional guidelines or codes and implications for radon control,” Proceedings of ASHRAE IAQ 91 Healthy Buildings, Atlanta, GA, ASHRAE, 228-229 (1991).

(CCSP 2009) Global Climate Change Impacts in the United States, U. S. Global Change Research Program, 2009

(Chew 2006) G. L. Chew, J. Wilson, F. A. Rabito, et al., Mold and endotoxin levels in the aftermath of Hurricane Katrina: a pilot project of homes in New Orleans undergoing renovation, Environmental Health Perspectives, vol. 114, no. 12, pp. 1883–1889, 2006.

(Colt 1998) J. S. Colt et al, Comparison of Pesticides and Other Compounds in Carpet Dust Samples Collected from Used Vacuum Cleaner Bags and from a High-Volume Surface Sampler, Environmental Health Perspectives Volume 106, Number 11, November 1998

(Colt 2004) J. S. Colt et al, Comparison of pesticide levels in carpet dust and self-reported pest treatment practices in four US sites, Journal of Exposure Analysis and Environmental Epidemiology (2004)14, 74–83

(Cummings 1989) J.B. Cummings, J.J. Tooley, Infiltration Rates and Pressure Differences in Florida Homes Caused by Closed Interior Doors When the Central Air Handler is On, *Proceedings of American Solar Energy Society 14 th National Passive Solar Conference, Denver, CO*, pp 392 – 396, June 1989

(Cummings 1996) J. B. Cummings et al, Uncontrolled Airflow in Non-Residential Buildings, FSEC-CR-878-96, Florida Solar Energy Center, 1996

(Daisey 2003) Daisey, J.M., Angell, W.J., and Apte, M.G. 2003. Indoor air quality, ventilation, and health symptoms in schools: An analysis of existing information. Indoor Air 13:53-64.

(Ebeling 1978) W. Ebeling, *Urban Entemology,* The Regents of the University of California, 1978

(Edwards 1999) C. Edwards, Modelling of Ventilation and Infiltration Energy Impacts in Mid- and High-Rise Apartment Buildings. Report by Sheltair Scientific Ltd. For Canada Mortgage and Housing Corporation, 1999

(Emmerich 2005) S. J. Emmerich et al, Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use NISTIR 7238

(EPA) Step Up to the Energy Star Indoor Air Package, http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/IAPBuild508.pdf

(EPA 2007) U.S. Environmental Protection Agency, Important Exposure Factor for Children: An Analysis of Laboratory and Observational Field Data Characterizing Cumulative Exposure to Pesticides, EPA 600/R-07/013, March 2007

(EPA 2009) U.S. Environmental Protection Agency, Indoor airPlus Construction Specifications, EPA 402/K-08/003, January 2009

(Fisk 1988) W.J. Fisk, R.J. Prill, O. Seppanen. "Commercial building ventilation measurements using multiple tracer gases." Ninth AIVC Conference, 1988.

(Goldman 2010) C. Goldman et al, Energy Efficiency Services Sector: Workforce Size and Expectations for Growth LBNL-3987E, Lawrence Berkeley National Laboratory, September 2010

(Gundel 2002) Lara A. Gundel, Douglas P. Sullivan, Gregory Y. Katsapov and William J. Fisk, A Pilot Study Of Energy Efficient Air Cleaning For Ozone, LBNL-51836, Lawrence Berkeley National Laboratory, November 28, 2002

(Harriman 2006) L. Harriman et al, *ASHRAE Humidity Control Guide,* ASHRAE, 2006

(Haverty 1976) M. I. Haverty, W. L. Nutting, Environmental Factors Affecting the Geographical Distribution of Two Ecologically Equivalent Termite Species in Arizona, The American Midland Naturalist, No. 1, January, 1976, pp. 20-27

(Hovorka 2004) Jan Hovorka Robert F. Holubb Martin Branis, Bruce D. Honeyman, “Tracing Outdoor/Indoor Penetration of PM2.5, PM1.0 by 210Po/210Pb”, Indoor Built Environ 2005 14;3-4:249–253

(Hu 2004) X. P. Hu, A. G. Appel, Seasonal Variation of Critical Thermal Limits and Temperature Tolerance in Formosan and Eastern Subterranean Termites (Isoptera: Rhinotermitidae), Environmental Entomology, 33(2):197-205. 2004.

(Johnson 2006) P. Johnson, Standard 62 IAQ Procedure: Reduced Outdoor Air for Auditorium, ASHRAE Journal, Vol. 48, May 2006

(Knowles 2008) Hal Knowles III, Realizing residential building greenhouse gas emissions reductions: The case for a Web-based geospatial building performance and social marketing tool, 17th Annual International Emission Inventory Conference: Inventory Evolution - Portal to Improved Air Quality

(Long 2001) Christopher M. Long, Helen H. Suh, Paul J. Catalano, Petros Koutrakis, Using Time- and Size-Resolved Particulate Data To Quantify Indoor Penetration and Deposition Behavior, Environ. Sci. Technol. 2001, 35, 2089-2099

(Meng 2005) Qing Yu Meng et al, Influence of ambient (outdoor) sources on residential indoor and personal PM2.5 concentrations: Analyses of RIOPA data, Journal of Exposure Analysis and Environmental Epidemiology 2005 15,17–28

(Mulrooney 2006) J. E. Mulrooney et al, Persistence and Efficacy of Termiticides Used in Presconstruction Treatments to Soil in Mississippi, Journal of Economic Entomology 99(2): 469-475 (2006)

(National Termite Survey), City of New Orleans Mosquito & Termite Control Board: National Termite Survey, Retrieved November, 2010 from: http://www.termitesurvey.com/whats_new.shtml

(NCHH) The National Center for Healthy Housing, http://www.nchh.org/Training/National-Healthy-Homes-Training-Center.aspx

(Ogg 2006) C. L. Ogg et al, Subterranean Termites: A Handbook for Homeowners,Cooperative Extension, University of Nebraska Lincoln (2006)

(Persily 1987) A.K. Persily, L.K. Norford. Simultaneous measurements of infiltration and intake in an office building, ASHRAE Transactions 93(2):42–56, 1987

(Peterson 2010) C. J. Peterson, Termites and climate change: Here, there and everywhere?, Earthmagazine, retrieved November 2010 from: http://www.earthmagazine.org/earth/article/30a-7da-2-10

(Pisaniello 1993) D. L. Pisaniello et al, A study of building structural features associated with high indoor air concentrations of organochlorine termiticides, Australian Journal of Public Health, vol 17 No. 3, 1993

(Quarles 2004) Stephen Quarles, Anton Tenwolde, Attic and Crawlspace Ventilation: Implications for Homes Located in the Urban-Wildland Interface, Woodframe Housing Durability and Disaster Issues, Las Vegas, Nevada October 2004

(Rao 2007) C. Y. Rao, M. A. Riggs, G. L. Chew, et al., Characterization of airborne molds, endotoxins, and glucans in homes in New Orleans after Hurricanes Katrina and Rita, Applied and Environmental Microbiology, vol. 73, no. 5, pp. 1630–1634, 2007.

(Rabito 2010) F. A. Rabito, S Perry, W. E. Davis, C. L. Yau, and E. Levetin, The Relationship between Mold Exposure and Allergic Response in Post-Katrina New Orleans, Journal of Allergy Volume 2010, Article ID 510380, 7 pages doi:10.1155/2010/510380

(Roberts 2004) J. W. Roberts et al, A Pilot Study of the Measurement and Control of Deep Dust, Surface Dust, and Lead in 10 Old Carpets Using the 3-Spot Test While Vacuuming, Archive of Environmental Contamination and Toxicology, 48, 16-23 (2004)

(Sapkota 2005) Amir Sapkota, J. Morel Symons, Jan Kleissl, Lu Wang, Marc B. Parlange, John Ondov, Patrick N. Breysse, Gregory B . Diette, Peyton A. Eggleston, and Timothy j. Buckley, Impact of the 2002 Canadian Forest Fires on Particulate Matter Air Quality in Baltimore City Environ. Sci. Technol. 2005, 39, 24-32

(Seppänen 1999) O.A. Seppänen, W.J. Fisk, M.J. Mendell, Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings," Indoor Air, 9, pp 226-252, 1999

(Shaw 1995), C. Y. Shaw, J. T. Reardon, Changes in Airtightness Levels of Six Office Buildings" ASTM STP 1255, American Society of Testing and Materials.

(Sherman 2002) M. Sherman, N. Matson, Air Tightness of New U.S. Houses: A Preliminary Report, LBNL-48671 Lawrence Berkeley National Laboratory 2002

(Sherman 2007) M. Sherman, Air Leakage of US Homes: Model Prediction, proceeding of Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference, December 2-7, 2007

(Shields 1999) H.C. Shields, C.W. Weschler and D. Naik, Ozone removal by charcoal filters after continuous extensive use (5 to 8 years), Proceedings of the 8th International Conference on Indoor Air Quality and Climate, Indoor Air 99, Edinburgh, Scotland, Aug. 8-13, 1999, Vol. 4, p. 49-54.

(Straube 2010) personal communication with the author on the topic of freeze thaw risk in insulated foundations

(Su 1998) Nan-Yao Su, R. H. Scheffrahn, A review of subterranean termite control practices and prospects for integrated pest management programmes, Integrated Pest Management Reviews 3, 1-13 (1998)

(Verma 2009) M. Verma et al, Biological alternatives for termite control: A review, International Biodeterioration and Degradation 63 959-972 (2009)

(Weaver 2009) C. Weaver et al, A Preliminary Synthesis of Modeled Climate Change Impacts on U.S. Regional Ozone Concentrations, Bulletin of the American Meteorological Society, December 2009, 1843-1863

(WAP 2009) U.S. Department of Energy, Office of Weatherization & Intergovernmental Program for the Weatherization Assistance Program, Weatherization Training and Technical Assistance Plan, WAP, December 2009

(Weschler 2000) C. Weschler, Ozone in Indoor Environments: Concentration and Chemistry, Indoor Air 2000; 10: 269–288

(Yates 1999) J. R. Yates III et al, New Technology for Managing the Formosan Termite, Cooperative Extension Service, College of Tropical Agriculture and Human Resources, University of Hawaii at Monoa (1999)

(Ziska 2003) L. Ziska et al, Cities as harbingers of climate change: Common ragweed, urbanization, and public health, JACI, 111:290-295