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Indoor climate and global climate change: Exploring connections

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SUMMARY

The connections between climate change and indoor climate are strong but not generally recognized. Climate change impacts local and regional atmospheric conditions including air quality and thermal conditions. Building climate control must respond to local climate and air quality to protect human health and support buildings' functional uses. Good indoor climate protects humans against local air pollution and the severe consequences of climate change. Technologies to control indoor climate requiring fossil fuel energy increase pollutant emissions including greenhouse gases; thus, indoor climate control impacts indoor and ambient air quality as well as global climate. Protecting humans and other living systems from the impacts of climate change involves adaptation and mitigation of the local and regional effects. Understanding and considering impacts of indoor climate control on regional air quality and global climate can reduce the negative impacts of building technology on building occupants as well as the entire global environment.

KEYWORDS

Indoor climate, Climate change, Indoor Air Quality, Human health, Greenhouse gas emissions.

INTRODUCTION: CLIMATE CHANGE AND INDOOR CLIMATE CONNECTIONS

Climate change and indoor climate[1] are inextricably linked. In fact, the linkage is quite strong and warrants far more attention than is currently paid by either global climate change or indoor climate researchers. This connection is even more often overlooked by policy makers.

Climate change, it may be argued, is the ultimate example of the "tragedy of the commons," the concept popularized in Garrett Hardin's 1968 *Science* article (Hardin, 1968). The Earth's atmosphere is shared by all living beings as a resource for gases necessary to sustain life and as a waste-processing system for pollution emitted by the metabolism of living organisms and even the slower change processes of non-living matter. Human use of the atmosphere for waste disposal somewhat uniquely extends beyond our biological metabolism to include our technological/industrial metabolism as well.

Many but not all of the most common means of controlling indoor climate in advanced industrial societies and increasingly in developing countries rely on technology and energy consumption that are major contributors to increased emissions of greenhouse gases (GHG). It is these emissions that are considered responsible for the changing global climate and dire projections of future climate (IPCC, 2007a, b). Indoor-climate-related examples of the tragedy of the commons include arguments that using more energy for optimizing IAQ or thermal conditions to improve worker performance or productivity and to improve comfort based only

[1] "Indoor Climate" in the 1978 conference by that name included indoor environmental conditions, especially thermal conditions, air quality, and acoustics. In this paper electromagnetic radiation, especially visible, ultraviolet, and infrared radiation, is also included.

on economic costs, that is, the cost is less than the benefit when only the internal costs and benefits are considered

Effects of climate change such as heat waves, excessive precipitation, flooding, drought, and the increased risk of wildfires all carry with them serious threats to human health and well-being. The known and projected impacts of the changing climate on human health will lead to even more drastic and widespread measures to control the indoor climate in order to mitigate climate impacts on human health. These kinds of responses, referred to in the climate change policy and science communities as "adaptation" and "mitigation," are likely to include such measures as increased use of cooling fans, air-conditioning, and "safe buildings" for children, the elderly and other susceptible populations (UK Department of Health, 2008). The link between indoor climate control efforts and climate change brings a new and compelling reason to re-examine our approach to controlling indoor climate.

Until recently, research seeking to define the optimum conditions for indoor climate has largely ignored the impacts of climate change on indoor climate and indoor climate control. It has also generally ignored the impacts of measures to control indoor climate on global climate change itself. Now, as both the scientific and governmental efforts to address climate change are accelerating, it is important to examine the connections between indoor climate and global climate change.

CLIMATE CHANGE FORECAST

Global emissions of carbon dioxide are still increasing. Estimates of future population growth and energy use are used as inputs to global climate models in order to project future climate change. Reviewing outputs from a range of such models, the Intergovernmental Panel on Climate Change (IPCC) has made the following predictions for the next century. Global mean surface temperature will rise by 1.4°-5.8° C. Warming will be greatest over land areas, and at high latitudes. The projected rate of warming is greater than anything humans have experienced in the last 10,000 years. The frequency of weather extremes is likely to change leading to an increased risk of floods and drought. There will be fewer cold spells but more heat waves. The frequency and intensity of El Niño may be affected. Global mean sea level is projected to rise by 9-88 cm by the year 2100. Many countries are working to reduce greenhouse gas emissions under the United Nations Framework Convention on Climate Change. Unfortunately, current international agreements are not sufficient to prevent the world facing significant changes in climate and a rise in sea levels (IPCC 2007a, b).

CLIMATE CHANGE IMPACTS:

Climate change has already impacted sea level, global average temperatures, and many observed natural and biological systems. Projections of future impacts are difficult to make and are associated with large uncertainty that increases as the time projected forward increases. Nevertheless, based on changes and impacts already observed, it is possible to identify the major features of climate change that will be most relevant to human health and to its protection in the indoor environment.

The IPCC Fourth Assessment Report (AR4) indicates that there will likely be increased drying in much of the subtropics and more rain in higher latitudes, continuing the broad pattern of rainfall changes already observed. The report also notes the improved agreement of the pattern of currently observed rainfall and that projected by the climate models. It is not clear but possible that the precipitation will be heavy (IPCC, 2007b).

Climate change: impacts on local and regional atmosphere

Warmer temperatures in the temperate regions will result in increased outdoor ozone. The future concentrations of air pollutants depend both on trends in emissions of primary and precursor pollutants and on trends in meteorological factors affecting pollutant dispersal and secondary chemical atmospheric processes. If local motor vehicle emissions increase, as they are now in rapidly developing countries, then emissions will increase to the extent that fossil fuels continue to be the major source fuel for motor vehicle engines. Reduction of ozone precursors such as reactive (volatile) organic compounds and oxides of nitrogen (NOx), as has been done in the U.S., especially in California, will reduce the total increase in local and regional ozone. Europe has already begun such reductions. However, the emissions in rapidly developing areas are increasing dramatically as access to motor vehicles, modern chemicals, and other technology spreads rapidly. It is expected that weather conditions associated with warmer temperatures will increase and thus also will the rate of production of ozone and its atmospheric concentrations. In the Northern Hemisphere, it is expected that annual and mean daily maximum 8-hour ozone concentrations will increase due to increased precursor emissions and climate change (Kovats, S, 2008).

Ozone

When weather is warmer, people without air-conditioning tend to open their houses to increase air velocity for the cooling effect of air movement. Ozone concentrations are higher indoors when ventilation rates are higher. Since warm weather and elevated ozone tend to coincide, exposure to ozone indoors will be higher in warmer weather. Weschler has reported that human exposure to ozone can be significantly comprised of indoor exposures and that indoor exposures may contribute to the elevated mortality and morbidity that occur during periods of elevated ozone (Weschler, 2006). Weschler and many others have reported that ozone even at relatively low concentrations reacts with many chemicals commonly found indoors to form more toxic and irritating compounds as well as fine and ultrafine particles (Weschler, 2000). Nazaroff et al reported that exposure of common household cleaning products to ozone at relatively low outdoor concentrations results in the reactions described by Weschler and mentioned above (Nazaroff et al, 2006).

Interrelations among Air Pollution, Stratospheric Ozone Depletion and Climate Change

Chlorofluorocarbons (CFCs) have been used as refrigerants in air conditioning systems. They are the leading cause of stratospheric ozone depletion, and also are powerful greenhouse gases. Both increases in global mean surface temperature and depletion of the stratospheric ozone layer are likely to affect the photochemical reactions that create ground level ozone or smog and in most cases aggravate the air pollution problem, to some extent negating the effectiveness of many air pollution control measures. Signatories to the Montreal Protocol have been highly successful in reducing emissions of ozone depleting compounds (ODCs). However, the substitute compounds, the hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are thought to contribute to anthropogenic global warming. On a molecular level, they are 10^5 times more potent GHGs than carbon dioxide. The Montreal Protocol calls for a complete phase out of HCFCs by 2030 but does not restrict HFCs. Since the CFCs are equally potent greenhouse gases, substituting HFCs for CFCs does not increase the rate of global warming. But many rapidly-developing nations in sub-tropical and tropical regions will likely experience increasing use of air-conditioning, and the increased use of any of these refrigerants will contribute to global warming.

Climate change: impacts on human health

The major mechanisms of impacts include heat waves, cold spells, severe storms, heavy precipitation, flooding, drought, vector-borne diseases shifting away from the equator (especially northward), air pollution, and food and water shortages. The relationships of climate change and health effects are shown in Figure 1.

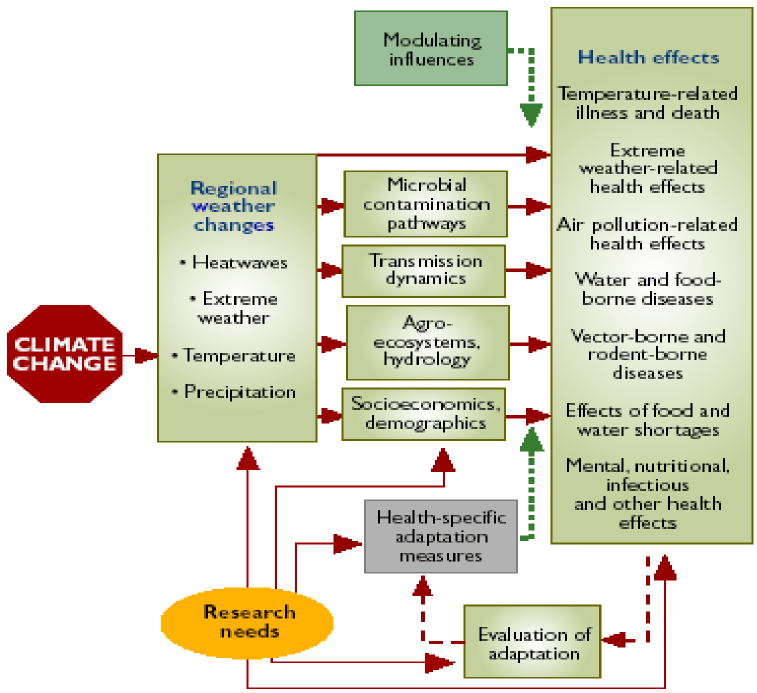

Figure 1. Climate Change and Human Health (WHO, 2005)

Climate change has the potential to impact health in many ways. While some of these are unpredictable, others (shown in the table below) are supported by considerable evidence.

Table 1. Causes and results of climate change impacts on human health

Weather Event	*Health Effects / Populations Most Affected*
Heat waves	Heat stress / Extremes of age, athletes, people with respiratory disease
Extreme weather events, (rain, hurricane, tornado, flooding)	Injuries, drowning / Coastal, low-lying land dwellers, low socio-economic status (SES)
Droughts, floods, increased mean temperature	Vector-, food- and water-borne diseases / Multiple populations at risk
Sea-level rise	Injuries, drowning, water and soil salinization, ecosystem and economic disruption/ Coastal, low SES
Drought, ecosystem migration	Food and water shortages, malnutrition / Low SES, elderly, children
Extreme weather events, drought	Mass population movement, international conflict / General population
Increases in ground-level ozone, airborne allergens, and other pollutants	Respiratory disease exacerbations (COPD, asthma, allergic rhinitis, bronchitis) / Elderly, children, those with respiratory disease
Climate change generally; extreme events	Mental health / Young, displaced, agricultural sector, low SES

The anticipated increase in ozone concentrations will result in an increase in attributable deaths and hospital admissions for respiratory diseases in the UK. Using a no-threshold model, about half of the predicted increase in health impact is due to changes in UK and European emissions rather than climate change. In the threshold models, however, most of the increase is attributable to climate change {Kovats et al, 2008}

Climate change: impacts on building environments

Major changes in annual and episodic precipitation totals, changing water table levels, flooding, and intense storms will increase the number of structures threatened by mould and other moisture-dependent organisms. This will result in deterioration of structural materials (e.g., by rust, dry rot, termites) as well as building contents. It will increase occupant exposure to moulds and its metabolites.

Building services (e.g., the level and frequency of heating, cooling, ventilation, and air-conditioning demand) will be affected by the changing climate. These changes will be reflected in increased equipment capacities and operational energy costs. To the extent that the energy is provided by fossil fuels, more GHG emissions and photochemical smog precursors will be emitted. To protect occupants, this, in turn, will require more filtration with an increased flow resistance resulting in yet further energy use requirements. Table 2 lists the major foreseeable impacts on buildings. It is noted that as temperatures become milder during the winter in many regions, the use of less heating with fossil fuels will offset some of the increased consumption of electricity during the summer for air-conditioning. In far northern climates like Scandinavia, Northern Canada, and Alaska, where very little air conditioning is used, at least under current and projected near-term-future conditions, there may actually be a net decrease in GHG emissions as the climate warms.

Table 2. Impacts of Climate Change: Consequences for Building Services

• Internal Temperatures / Comfort – Mean temperatures will increase improving winter comfort conditions, but causing problems with overheating in summer when *careful design will be needed to avoid full* air conditioning. • Energy Consumption – Winter energy consumption for heating will reduce, but use of air conditioning in summer could offset this. • Condensation, Mold Growth: Condensation and mold growth may decrease. • Internal Pollution: Higher temperatures could increase problems with indoor air quality; this could have health implications for occupants. • Water Supply: Reduced summer water supply in the South East US • *Legionella* Risk: Use of air conditioning and warmer and more humid internal environments could lead to increased risk of *Legionella* problems.

MITIGATING CLIMATE IMPACTS ON HUMAN HEALTH

Adaptation and mitigation are major strategies to address climate change impacts. Adaptation will include design, construction, and operation of buildings as well as education and other community level activities to encourage populations-at-risk to use cooling fans, seek cool shelter, or otherwise protect themselves during heat waves. Action has already begun in Europe following the disastrous, widespread effects of the heat wave of 2003, blamed for more than thirty thousand excess deaths. Strategies call for having fans on hand in advance of a heat wave as this was found far more effective than efforts to distribute them once the heat wave begins.

Trends in residential cooling energy demand

Energy demand for residential space cooling accounted for 6.4% of total electricity demand in the OECD in 2000. In the U.S., prior to 1951, virtually no home had air-conditioning (a/c). In 1951, the first room air conditioner was manufactured. In the US, the share of air-conditioned houses doubled from 1978 to 1997, from 23% to 47%.. Air-conditioning is being used more often: the share of houses with central a/c used "all summer long" rose from 33% in 1981 to 52% in 1997. There is a strong trend towards central rather than room a/c. By 2001 76% of all housing units had some type of a/c — a 34 percent growth from 1990. In Japan, air conditioning represents 23.9% of the residential electrical energy demand. The majority of Japanese households have a/c, on average, two room a/c units. 27% of Australian homes have a/c. Europe has very low rates, around .02 per household on average, although there was a 7-fold increase over the 1990s (Waide, 2003). There many opportunities to reduce energy demand for indoor climate control, as shown in Table 3.

Table 3. Opportunities for Improvement

Dominant paradigm today:
central, forced-air system
heating by natural gas combustion
compressor-based cooling
ventilation by infiltration and natural ventilation
Alternatives to reduce climate impacts:
passive heating, cooling, and ventilation (control)
design: orientation, fenestration, shading, materials
thermal mass buffers diurnal temperature swings
preconditioned air: earth tubes & sunspace rooms
radiant thermal conditioning systems

DISCUSSION

Climate change and indoor climate are strongly connected and have many characteristics in common, most obviously, their effects on human health. It is important to recognize that the means of adapting to the threats posed by climate change and indoor climate are themselves linked to the causes of both. The indirect effects of both also affect and contribute to the others. Both are characterized by the non-linear processes, for example, due to feedback mechanisms like glacial melting in Greenland, or like outdoor air quality, ventilation rates, filtration, and pollutant source emissions and concentrations.

Indoor climate and climate change affect the health of people in developing countries far more than in more developed ones. Many of the means of mitigating the adverse effects of climate change and indoor climate result in exacerbation of the conditions leading to climate change as well as reducing the potential for more benign solutions. This kind of dynamic interdependence is not unique to these two environmental concerns that are the focus of this paper but is common to many environmental problems. To paraphrase American naturalist John Muir: "everything on Earth is hitched to everything else on Earth.

"Indoor climate" has become a far more important "environmental" issue since the first "Indoor Climate" conference held in Copenhagen 30 years ago. At that time, indoor climate applied primarily to thermal conditions, but growing awareness, especially in Denmark, of the importance of indoor air quality led to the inclusion of many papers on indoor air pollutant sources and indoor air quality in that conference. Since that time, far more has been learned about IAQ and thermal conditions and their impacts on occupant comfort, health, and satisfaction. The Indoor Air 'xx conference series is now dominated by papers on indoor air quality although thermal conditions and comfort continue to be significant parts of the conference while papers on acoustics and illumination are now rare.

Over the years there has been increased recognition of the interactions between indoor air quality and thermal conditions and the resulting occupant responses. Yet far too little research has been done on the interactions. Building problem investigators know that occupant reports of problems with thermal conditions or air quality are often intertwined or misidentified.

Strategies that focus only on indoor climate control or even more narrowly focus only on IAQ or thermal conditions and ignore the impacts on climate change are ultimately self-defeating. There are vastly different approaches in developing and developed countries and different impacts of indoor climate and climate change on the populations in each. Increasing temperatures in developing countries along with increasing economic development are resulting in increasing use of air-conditioning and the associated energy costs and environmental impacts of energy technologies.

Buildings are responsible for a significant fraction of fossil fuel consumption and related GHG emissions globally. Energy use in buildings accounts for approximately 40% or more of total energy use in the U.S. and relatively similar proportions in other developed countries. Energy is used to condition indoor climate: to humidify dry air or de-humidify moist air, to operate fans, to thermally condition ventilation air that is deemed too warm or cool for indoor climate comfort conditions. It is used for ventilation and for cleaning or thermal conditioning of outdoor air. It is used for illumination. A significant fraction, 20 to 25% of building energy use is for “plug loads,” equipment, appliances, computers, and other devices that are not part of the building or its design. In the U.S. buildings' contribution to total U.S. GHG emissions are estimated at 40% to 49%. Measures to mitigate the human contribution to GHG emissions will increase pressure to reduce buildings' electricity and on-site combustion based on fossil fuel energy sources with concomitant impacts on indoor climate (IAQ, thermal conditions, and illumination).

Solutions

Designers and building operators with accurate information on the GHG emissions implications of various options available to them can make decisions that will reduce carbon emissions as well as reducing energy use. The development of accurate tools for estimating carbon emissions will enable designers to balance the benefits of available energy alternatives for achieving improved indoor environmental quality. Use of such tools may improve carbon emissions estimation by 10 to 25% or more compared to the use of annual average values more commonly used in the U.S. and in most developed countries. Thus, a balance between indoor environmental quality and reduced GHG emissions can be more attainable.

CONCLUSIONS

Buildings need to shelter people from the effects of climate change, heat waves, cold spells, air pollution, and floods. There is no question that providing this shelter must be done with the minimum use of fossil fuel combustion in order to avoid further exacerbation of the anthropogenic contribution to global GHG concentrations. There is a synergy in society-wide, low-pollution emission strategies including lower emissions from motor vehicles, electric power plants, and industrial installations. This would result in lower smog, and particle concentrations making natural ventilation more reasonable due to cleaner outdoor air and allowing lower energy use for conditioning ventilation air, lower energy consumption, etc.

Considering the connections between the indoor climate, outdoor climate and atmosphere, and the global climate requires an expanded scope for building research and practice, one that considers building ecology – the dynamic, interdependent relationships between the indoor environment and the general environment (Levin, 1995). There are many options to reduce energy consumption and carbon emissions. Most are cost effective, mostly in the short-term. They can improve the quality of life with less time commuting and flying and better air quality. Ventilation and thermal comfort standards must be revised to facilitate and anticipate these changes and to provide an updated set of targets for building design, construction, and operation that will provide healthy indoor environments while protecting the health of the Earth and all its inhabitants.

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