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Preview

Magic Walls

Andrew Sonta[1,*]
[1]Data Science Institute, Columbia University, 550 W 14th St, New York, NY 10027, USA
*Correspondence: andrew.sonta@columbia.edu

SUMMARY

Reducing energy demand on buildings' heating and cooling systems is fundamental to reaching a carbon neutral future. Writing in *iScience*, Xu and Raman show that by controlling radiative heat flows in buildings with novel materials, we can expand the thermal conditions in which we feel comfortable, thereby reducing energy demand on building systems.

Buildings and humans have a complicated relationship. A large proportion of humanity spends almost all its time—in the United States, about 90 percent—in buildings.[1] But buildings are not perfect. Environmentally, the building sector is one of the largest sources of energy inefficiency.[2] And from the human perspective, buildings often do not work as planned. In office buildings, for example, complaints of thermal discomfort—being too hot or too cold—are rampant.[3]

The environmental and human challenges in buildings sometimes even work hand in hand. One can see this effect in summertime Florida, where it is not uncommon for people to carry a sweater, not for fear of abrupt weather changes, but rather to shield against the overcooled interiors of movie theaters and malls. The overzealous air conditioners cool past the point that makes the most economic, environmental, and human sense. The reasons for this specific kind of building-operation blunder are many (one is that mechanical engineers often design heating and cooling systems for male office workers wearing suits, even if most summer Floridians are wearing tank tops and flip-flops). But the fix is fairly simple: turning up the thermostat a few degrees would save energy and make people more comfortable.

This alignment between environmental and human goals in buildings is not always so. We do need to provide a level of energy-intensive heating and cooling that protects us from harsh outdoor environments. Adjusting the thermostat to the appropriate level can only save so much energy. To reach our sustainable energy goals, we need to innovate and broadly deploy more efficient building design and modes of operation. But paramount to the success of these technologies will be ensuring they simultaneously emphasize our human needs—integrating our environmental and human goals.

Writing in *iScience*, Xu and Raman[4] exhibit this kind of innovation by studying creative building operation that focuses on controlling radiative heat flows. Instead of focusing on the physical heating and cooling systems themselves, they put the experience of the occupants first. By doing so, they show that we can turn back our thermostats even further—making building systems work less hard and saving even more energy in buildings. Their insight was taking advantage of the peculiarities of what it means to feel hot, cold, or comfortable.

Xu and Raman's research involves tuning an unconventional heating and cooling lever that involves heat transfer through radiation. Key to understanding this innovation is realizing that our thermal perceptions are not solely dependent on temperature. Thermal sensation is all about rates of change—how heat flows between our bodies and our surroundings. In most settings, unless it is dangerously hot, we lose heat from our warm bodies to our relatively cooler surroundings. Heat transfer primarily occurs across three kinds of channels: conduction, convection, and radiation (Figure 1A). Conduction is dependent on material properties. Sitting in a pool that is 72°F/22°C feels colder than sitting in a room at that same temperature because water is a better conductor of heat: it pulls heat away from our warm skin at a faster rate. Similarly, a breeze makes us feel cooler because it increases the rate of convection between our skin and our surroundings.

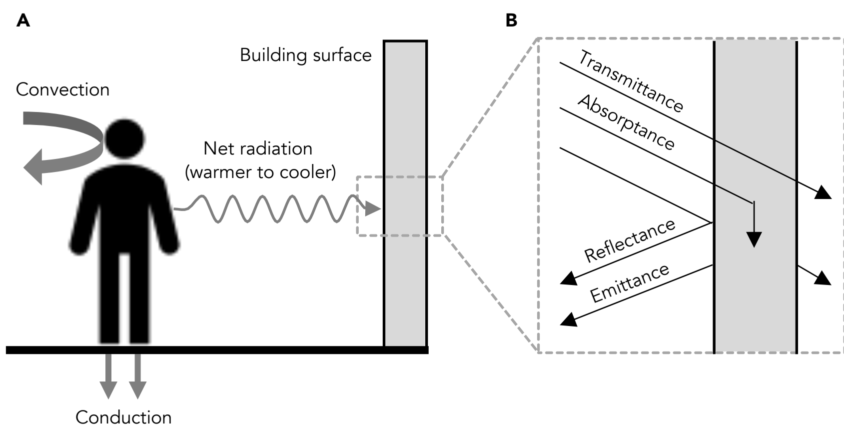

Figure 1. Overview of heat flows relevant to thermal comfort in buildings.
(A) Schematic of conduction, convection, and radiation.
(B) Radiative properties of building surfaces.

Our experiences of radiative heat transfer are less intuitive, but still common. All things radiate energy, and objects anywhere near room temperature radiate energy in the infrared spectrum. If two objects are next to each other, the net balance of radiative heat transfer will be that heat flows *from* the higher-temperature object *to* the lower-temperature object. In buildings, our skin tends to be warmer than our surroundings, and therefore we lose heat to our surroundings through radiation.

A critical aspect of radiative heat transfer is what happens to that radiation once it reaches another object. An object can transmit, absorb, and reflect incoming radiation; importantly, any absorbed radiation is eventually emitted (Figure 1B). The breakdown of these modes (which must sum to 100%) depends on material properties. Opaque walls, floors, and ceilings have very low transmittance, so the key trade-off is between reflectance and absorptance/emittance. A material that reflects more radiation necessarily absorbs/emits less—this is called a "low-emissivity" surface. A "high-emissivity" surface, by contrast, reflects very little radiation. Building materials have always been thought of as having fixed radiative properties (usually high-emissivity, low reflectance). But in their work, Xu and Raman asked the following question: what would happen if we leveraged novel materials that are able to dynamically change their emittance properties?

Materials with mutable radiative characteristics are important because a surface's temperature and emissivity can impact our thermal sensations. For example, imagine someone who is feeling cold. This person is cold because they are rapidly losing heat to their surroundings. If this person stands near a building surface, their thermal sensation will depend in part on the radiative properties of that surface. If the surface is like most building surfaces—high-emissivity—it will absorb most of the radiation leaving the person. This high rate of radiative heat transfer from the person to the surface contributes to the sensation of feeling cold. If, however, the surface had low emissivity, much of that thermal radiation would be reflected back to the person, helping them feel warmer. When it's cold outside, a low-emissivity surface would be desirable (Figure 2A). When it's hot, by contrast, a high-emissivity surface would create more comfort, as this would increase the amount of heat lost to the environment (Figure 2B). The traditional paradigm in building design is that surfaces have a single set of radiative properties. Recently, however, researchers are showing that "flexible IR electrochromic devices based on conducting polymers"[4] can be used to dynamically change the radiative properties of materials.[5,6] While these materials have never been physically integrated into architectural design, and research is still required to ensure they are suitable to building applications, they could offer a new path toward building energy efficiency.

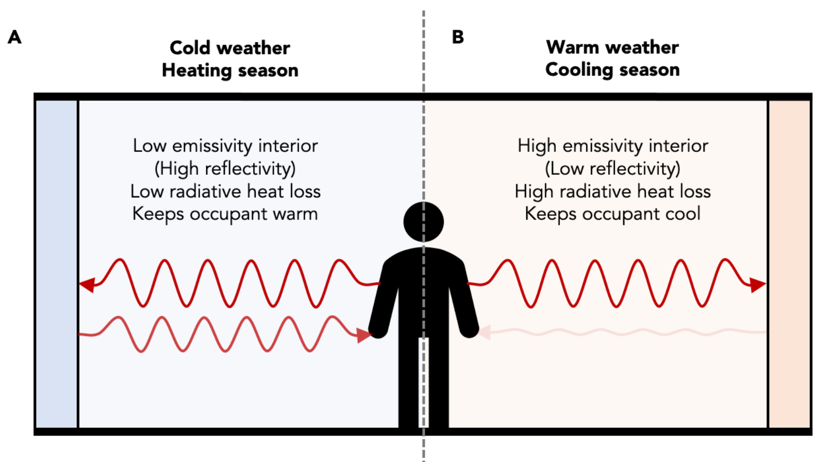

Figure 2. Materials with different radiative properties and their effect on thermal comfort. Adapted from Xu and Raman.[4]

(A) Low emissivity walls reduce radiative heat loss.

(B) High emissivity walls maximize radiative heat loss.

Xu and Raman ran a set of simulations to test how these emissivity-flexible walls impact building operation and energy consumption. In cold-weather scenarios, as the wall emissivity decreased from 0.9 to 0.1, they showed that radiative heat loss can be reduced by about 24% for an individual in a room. With these low-emissivity walls, radiation from our bodies reflects back to us, making us feel warmer. This in turn can enable the building's thermostat setpoint to decrease up to 6.5°C from the standard heating setpoint of 23°C. With this lower setpoint, they found, the energy required for heating can be reduced by about 34–37%, depending on the climate.

Xu and Raman also highlight the importance of being able to reverse this emissivity lever in the summer when cooling is needed. If the surfaces retained their low emissivity of 0.1, occupants would lose less heat to their surroundings and feel too warm, causing the air conditioning to work hard and creating a 34–35% energy penalty, compared to reversing the emissivity to 0.9.

A drawback of the simulations is that they do not test real-world energy savings. But they do show what is theoretically possible, setting the stage for future studies that test empirical outcomes.

As Xu and Raman show, the upshot of these novel materials is that we can drastically expand the set of temperatures in which we feel comfortable. In the context of broader energy-saving strategies in buildings, this could not only directly impact energy consumption in the built environment, but also complement other means for achieving energy efficiency. For example, sustainable design strategies that leverage the concept of "passive design"—design that uses the sun and wind for heating and cooling—is often critiqued for letting temperatures swing outside the tight bounds we have become accustomed to with modern mechanical systems.[7] But if we can couple these passive strategies with materials that expand the set of temperatures in which we are comfortable—as Xu and Raman's research demonstrates—we can make sustainable design strategies like passive design suitable to a broader range of settings.

Because these innovative materials work through different physical mechanisms than most heating and cooling systems, their promise is not only in their direct energy savings potential, but also in their potential to work alongside other building energy innovations. Finding and deploying these synergies has the potential to drastically accelerate our progress toward decarbonizing the built environment.

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