SFDPH
Environmental HEALTH

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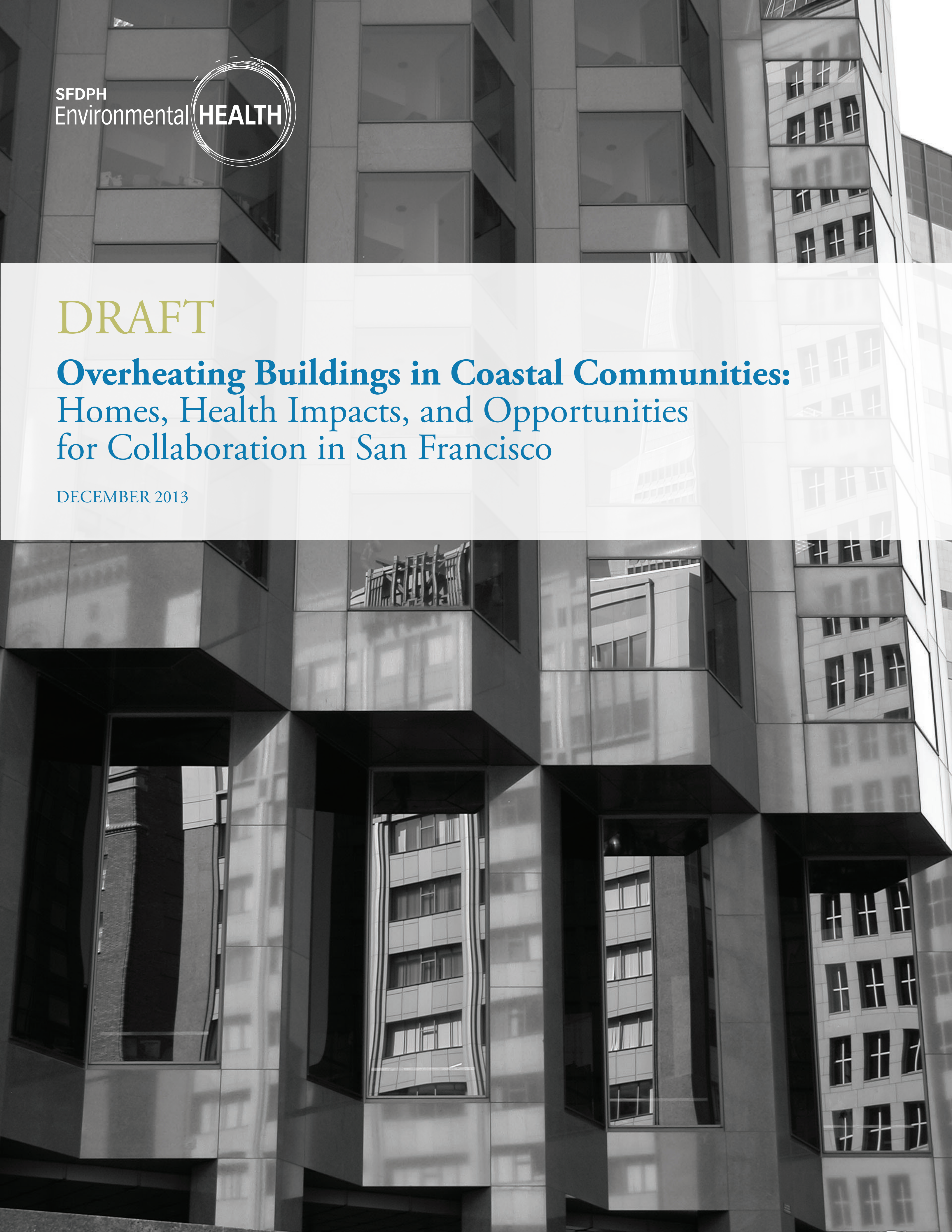
Overheating Buildings in Coastal Communities:
Homes, Health Impacts, and Opportunities for Collaboration in San Francisco

DECEMBER 2013



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Acronyms

ASHRAE	formerly the American Society of Heating, Refrigerating and Air Conditioning Engineers
HIA	Health Impact Assessment
HVAC	Heating, Ventilation, and Air Conditioning
SF	San Francisco
SFDBI	San Francisco Department of Building Inspection
SFDPH	San Francisco Department of Public Health
WGBT	Wet Bulb Globe Temperature

Keywords

indoor environmental quality, thermal comfort, heat stress, residential buildings, climate change, health impact assessment

Contents

Foreword

Extreme heat causes more death in the US than hurricanes, lightning strikes, tornadoes, earthquakes, and floods combined.[1] These heat waves are "silent killers" for good reason. But extreme heat events fail to grab national headlines and offer no dramatic video footage of devastated communities. Previous heat wave narratives portray victims as "the poor, the old, residents of abandoned and violent neighborhoods who lived alone, lacked access to transportation and lacked air-conditioning."[2]

How can a coastal community, like San Francisco where residents are used to cool summers and regular fog, begin to address the threat of a rapid increase in the number of extreme heat days per year? What building design elements could mitigate the impacts of extreme heat events? What other initiatives are needed to promote healthy and heat wave-resilient home environments?

We use health impact assessment (HIA) and design thinking frameworks to collect evidence and elevate the issue of how an overheated home impacts health. We bring together issues of climate change, modern building trends, and the potential health effects on San Franciscans. We use this HIA, and our future planned initiatives, to ask ourselves two questions:

- Are we effectively creating awareness on the connection between overheated buildings and health?
- How do we ensure residential buildings are built and retrofitted to maximize occupant comfort as the climate warms?

Our process-oriented HIA lays the groundwork for answering these two questions. In using this report and presentation as a communication tool, we challenge the wider ecosystem of actors to collectively address the threat of overheated buildings and its impact on health.

A collective and holistic approach to understanding and addressing overheated buildings could reduce heat-related health risks, energy demands, and costs on heat-related medical and energy expenses. Whether optimizing comfort for everyday living or ensuring buildings guard against future heat waves, protecting the public from heat impacts is an urgent and clear need.

Background

The urgency to mitigate the health impacts of climate change, increased heat vulnerability of coastal communities, and reported overheating problems at a modern, high-rise condominium building in San Francisco, serve as primary drivers for the HIA. The focus on modern building trends to implement an open-floor concept, tighten the building envelope, and add floor-to-ceiling windows without compensatory cooling design elements, adds to the need to inform building design with an occupant health lens.

During the July 2006 California heat wave, 650 people died due to heat-related causes.[3] While San Francisco reported no heat-related deaths, this city and other cooler coaster regions bore disproportionately higher risks for heat-related morbidity relative to other California regions.[4] This outcome is noteworthy in San Francisco because the temperature never exceeded 95°F. Sacramento had 11 consecutive days exceeding 100°F during the same period but lower morbidity risks.

San Francisco's weather is more famously associated with the "Coldest winter I ever spent was a summer in San Francisco" quote, than any other extreme heat event in recent memory.[5] Yet, San Francisco, and neighboring Alameda County, contain census tracts that are some of the most heat vulnerable in the country to heat waves.[6]

As building envelopes become increasingly air tight and insulated and window facades occupy a greater surface area of a building, home overheating is a growing concern.[7] With the Bay Area expected to experience 39 extreme heat days by 2050[8] and with urban heat island effects intensifying, additional inquiry into the issue of overheat is timely and necessary.

We hope this guide serves as a starting point for multi-sectoral collaboration in climate change, residential overheating, and health. We hope this exploratory and process-oriented HIA engages stakeholders to collectively identify solutions and act. In the process, we can save costs, reduce energy demands, and protect health during the next 2006-type heat wave.

Screening

Even during relatively mild summers in San Francisco, some occupants are exposed to hazardous overheated conditions.[9] In 2008, the owners association (representing owner-occupants) of a 2006 South of Market high-rise condominium called the Beacon in San Francisco, alleged in a lawsuit that "units overheated because of defective ventilation and window design"[10] among other complaints. A few years later Board of Supervisor Jane Kim, at the request of some of her constituents who lived in the Beacon, called on SFDPH to examine indoor environmental quality issues, including overheated buildings. SFDPH report findings were surprising. While high temperatures in the city in September 2010 ranged from 67°F to 81°F, some units in the Beacon experienced indoor temperatures exceeding 90°F for more than 7 consecutive hours over a 3 day period. One unit reported temperatures in excess of 80°F for 95 consecutive hours over a similar 4 day period. The confirmation of this health hazard in a modern, residential building contributed to the need for more information on how this event could occur.

Health Impact Assessment
A combination of procedures, methods, and tools used to anticipate health effects and inform decision-making.

Design thinking
A style of thinking rooted in empathy used to analyze information, contextualize problems, create platforms for insight, and distill useful solutions.

We selected overheating and health as an area of inquiry because:

- The pathways and related policies between climate change and overheated buildings are under researched, especially in US coastal communities.
- Recent residential building design trends (e.g., the Beacon) to achieve aesthetic and energy efficiency goals could compromise the health and well-being of occupants.
- Proactively addressing the health impacts of climate change, with a focus on indoor environments, is an urgent need.

Data on heat-related illness and death at hospitals is commonly underreported or misdiagnosed for several reasons.[11,12,13] Building inspectors cannot enforce overheated buildings laws because they generally do not exist, especially in a region where under heating, not overheating, is a primary habitability concern.[14] Because a formalized channel for people to complain about overheated buildings either does not exist or is little used, complaints of overheat are under reported, much less systematically analyzed. The traditional public health approach to addressing heat-related illness through passive surveillance is ill-suited to proactively addressing future health impacts of extreme heat.

Scoping

We draw on HIA and design thinking frameworks to systematically identify issues and methods for the assessment stage, but also to help organize our long-term thinking around understanding the problem of overheated buildings. This HIA incorporates information from a multitude of sectors: public health, indoor environmental quality, building science, and climate change. Further, we use HIA and design thinking frameworks to:

- Help identify and call attention to the issues of overheated buildings and health as a problem in a coastal community
- Find and present data from occupants and experts about this issue
- Develop a communication tool that informs stakeholders about this issue in a way that is simple and easy to understand (see Figure 2: Interactive crowdsourced map)
- Facilitate brainstorming to promote collaborative engagement for action.

We define and use design thinking as a loose framework that moves beyond the typical ways of analyzing information and problem solving. The approach is rooted in empathy and human-centered. Design thinking considers the context of the problem, provides a creative and open platform for insight, and distills pragmatic and useful solutions.[15] While HIAs typically focus on population-level health impacts, design thinking shifts this focus by placing human (user) experience impacts at the center of any problem-solving effort. This HIA stimulates the challenging, multi-dimensional issue of overheated buildings, in part by using design thinking's flexible process and outcome tools discussed in this section.

CHOOSING DATA SOURCES

Unlike many HIAs where the "burden of disease" data is more readily available, minimal data exists in the area of overheated buildings and health, especially in coastal San Francisco. We analyzed publicly available data on social media sites like Yelp, Apartment Ratings, and SocketSite comment threads to obtain a "snapshot" on the health impacts of feeling overheated in buildings. We also talked with low-income seniors at a local community center in the South of Market area about their experience with heat. Figure 1 represents our data sources for this health impact assessment.

Due to the lack of official heat-related illness data, we found in-depth interviews and user experiences on social media extremely valuable, especially when woven together with our literature review.

Figure 1: Data sources

Health Impact Assessment

SOCIAL MEDIA

Website	Keywords	Additional "match" criteria
http://yelp.com http://apartmentratings.com http://socketsite.com	heat, hot, air, warm, window, summer, sleep, condition, ventilation, sun, A/C	• Unit located in San Francisco? • Reviewer likely lived in the building? • Reviewer talking about the unit? For example, "It was Sunday and there was construction" would be excluded from the analysis.

LITERATURE REVIEW

Methods: Keyword searching combined with snowball searching (finding references based on papers identified by previous searches)
Keywords: climate change, housing, building, health (impact), overheating, indoor, (extreme) heat, urban heat island, vulnerability, heat stress, thermal comfort, heat wave, energy efficiency

INTERVIEWS

Method	Organization (for identification purposes only)
phone	Building and License Enforcement, City of Chicago
email	California Air Resources Board
phone	Canadians for Properly Built Homes
email	Center for the Built Environment, UC Berkeley
in person	David Baker Architects
phone	Department of Housing and Community Development, State of California
email	Healthy Heating, Inc.
email	Konstruct West Partners
phone	Taylor Engineering, LLC
in person	West Bay Filipino Multi-Services Center

HOW DESIGN THINKING ENHANCES HIA

Understanding the multi-dimensional overheat problem coupled with the numerous actors who plan, construct, occupy, sell, and regulate buildings, led us to revise our HIA objectives. Instead of identifying solutions, we identify paths for collaboration. How can the multitude of actors be more engaged so that a collective approach to addressing overheated buildings takes root?

1. "Flat" team structure yields more and better ideas
The application of non-hierarchical exercises influenced by Frog's Collective Action Toolkit[16] ensured a high level of shared idea and knowledge exchange. Internal team members seamlessly built upon one another's ideas. Ensuring a collaborative environment early on in the HIA project set a tone that encouraged feedback loops at all stages of the project and remains a strength for facilitating future feedback.

Drawing on design thinking principles, we brainstormed extensively aspiring for "quantity over quality" when generating ideas. Inspired by the "fail faster, succeed sooner" model, our internal team reserved judgment of the ideas. Design thinking supports the concept that all ideas have value and that an "impossible" idea can be altered into a realistic collaborative solution.

2. Visual thinking = visual literature review
Note-taking and visual thinking (sketches, images) were encouraged and accessible to all team members, which further encouraged brainstorming and free-flowing thinking around the HIA, both inside and outside the office. For example, we found our visual literature review exercise helpful in not only distilling the main points of the research articles, but useful for physically grouping themes on a wall and identifying information gaps. For example, while health impacts of overheating are well-defined in the literature, information on the regulation of overheated residential environments is generally non-existent or under-enforced.[17]

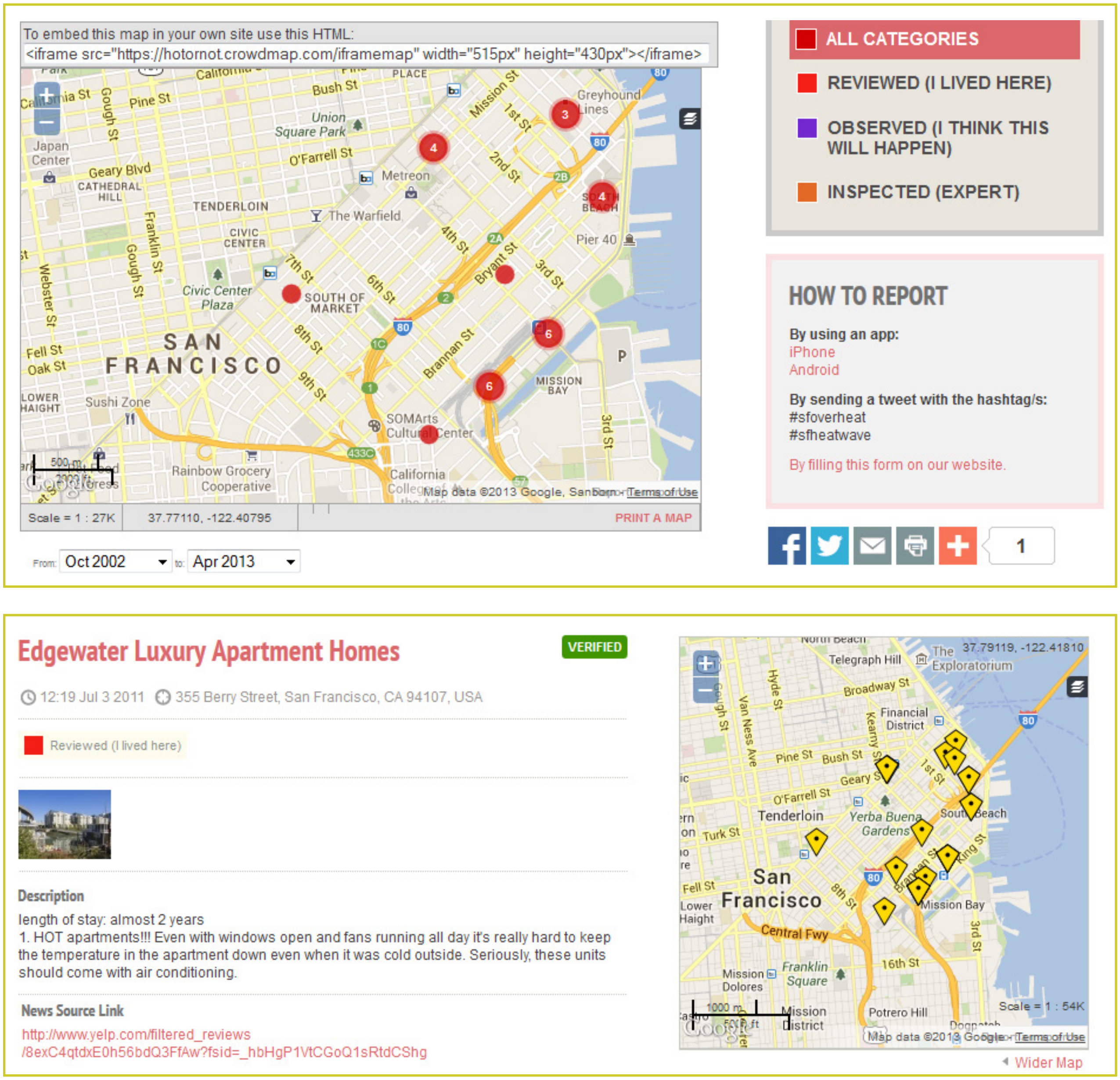
Visualizing scientific journal findings through an image or existing chart contributed to pro-actively framing information. This aided in developing a communication tool for informing stakeholders about overheated buildings and health. For example, comparing a car to a home partially highlights the limited thermal comfort design protections in homes relative to cars (see Table 1: Comparison of design elements in a car and home).[18] More importantly, it provides an alternative frame for thinking critically about what makes thermal comfort and health so important in cars but not homes.

Table 1: Comparison of design elements in a car and home

Category	Car	Home
Heated and cooled seating	yes	no
Operable windows	yes	sometimes
Air-conditioning	yes	sometimes
Well-located registers/grills	yes	sometimes
Average transaction cost (US)	$31,252[19]	$272,900[20] (higher if using SF home sales data)
Daily time spent inside	8%[21]	70%

3. Displaying information in multiple formats
We leveraged the power of multiple mediums to organize and display on-going information and ideas. Envisioning sessions included sketches of a mobile application and an interactive crowdsourced map (see Figure 2).[22] Both iterations demonstrated thinking about data collection, visualization, and communication around which buildings in San Francisco experience overheating.

Figure 2: Interactive crowdsourced map
(Source: https://hotornot.crowdmap.com/main))



Much like HIAs that take a comprehensive approach to health, integrating the design thinking process pushed for more holistic collaborations. Different concepts and questions were always "baking" and possible collaborations were brainstormed at multiple scales:

- Local - Phone apps could crowdsource data on overheated units and inform prospective home buyers and renters on Trulia
- Statewide - How changes to California's Residential Building Energy Efficiency Standards (Title 24) could incentivize exterior shading and reduce overheating?
- National - Are residential energy efficiency funders, which promote tightening of the building envelope, considering potential excessive heat gain due to warmer climates in their grant proposals?

4. Reflections on HIA and design thinking

Overall, we needed a process flexible enough to incorporate and value human feelings and experience and health impacts as much as the social and environmental conditions in which extreme heat events take place. We also needed to be strategic enough to compile information into useful categories and formats which could facilitate action.

The coupling of HIA with design thinking offers significant opportunities for a more nuanced understanding of a complex problem, innovative insight generation, and flexibility. HIA practitioners are notable in their willingness to be inter-disciplinary and embrace methods and processes originating in other sectors. Applying design thinking principles to an HIA project advances inter-disciplinary thinking and promotes the collective aim to ensure informed decision-making.

Assessment

We organize our assessment with a series of questions around the:

- Impact of heat on health
- Building's role on the indoor thermal environment
- Causes of overheated buildings.

First, we discuss how experts helped bound our research aims and organize our findings. We intersperse social media blurbs throughout the assessment section to capture occupant experiences of feeling hot indoors. The user comments highlight the situations, emotions, and frustrations that often accompany experiences of people living in overheated buildings.[1]

THE ROLE OF TALKING TO EXPERTS

We interviewed 10 experts using purposive, expert sampling to understand how they manage overheating or problematic building performance in their particular industry (see Figure 1: Data sources). Using in-depth interviews and a semi-structured questionnaire, we found a wide variation in their approach and proposed solutions to problem buildings. One area of agreement is that overheating in homes is a complex and largely unaddressed issue in residential settings. We list a variety of paraphrased key perspectives below, in part, to illustrate the breadth of the stakeholders' knowledge and highlight inter-related problems involved with overheated buildings:

Different agendas, same building

This is an extreme example but shows how building performance problems might emerge due to competing agendas.

> "Let's say the developer wants to maximize floor area to reduce building height for maximum sales potential. The envelope engineer wants to minimize air infiltration and reduce window areas for energy performance. The architect wants to locate registers (grills) out of sight for aesthetic reasons. The heating, ventilation, and air conditioning (HVAC) engineer wants to use a specific HVAC system because he has been trained in it. The building operator wants to individualize the systems to each tenant for billing reasons. And the tenant just wants to use the space without thinking about these issues.

[1] These comments do not reflect the views of all tenants in the building. There is significant variation in exposure to heat within the same building due to varying levels of sun exposure, occupants' own perceptions of what feels "hot," occupants' clothing, among other factors. Anecdotally, overheating in San Francisco dwellings tends to be underreported for the following reasons: 1) for condominium owners, openly expressing overheating problems could negatively impact the sales value of the unit 2) in the event that a building is in litigation, banks may be less inclined to finance the purchase for new buyers, thereby alienating the tenant-complainant from other tenants 3) since overheating problems are sometimes partially a result of costly structural building deficiencies, occupants are unwilling to "rock the boat" and talk to their landlord or homeowners association 4) renters in this city (64% in the 2010 Census) may also express dissatisfaction with an overheated building by moving, thereby removing themselves from the problem source.

[2] Due to the small sample size, we do not attribute comments to specific persons or organizations.

Because of competing agendas, you have a lower ceiling height which means the indoor contaminants remain at breathing level instead of moving higher. There might be insufficient ventilation because of small windows and the tight building also means that building material off-gassing does not have anywhere to go. The mechanical ventilation does not achieve its purpose because it is not located to maximize efficiency and the HVAC system is antiquated. The filters, which are now in the tenant space, are not replaced as it is no longer the responsibility of the building operator but the tenant. And the tenant who moved into the space has not been educated on these indoor environmental quality issues. All of this happens before the medical problems might emerge and even then, few indoor environmental quality thresholds exist. Now, that's how you end up with a big problem.

Contemporary and modern building styles

Bad building design, especially excessive unshaded glazing of windows is often to blame.

This problem continues to occur everywhere [even with California's new energy efficiency building codes] because so many architects and their engineers are locked in their HVAC/modernist box. Unless you have a lot of electricity and air-conditioning on hand, such buildings are not survivable in warm, sunny weather. It is not rocket science but the involved professions can't see the flaws even when their fancy radiance simulations make it perfectly clear that the interior spaces are bathed in direct sunlight. Interior blinds, when present, help protect the occupants , but they don't solve the fact that solar heat gain is liberated in the space.

Residential buildings are a low priority

In the building design world, homes are the lowest priority area, even though people spend the most time in them.

The reasons commercial buildings drive most of the research on thermal comfort and heat stress is because the productivity of workers, specifically profits, can be impacted. Other barriers which prevent wide-scale heat-protective innovation in homes include barriers to access (privacy), lack of building control and data, and varying thermal comfort expectations.

Overheated single-room occupancy hotels

On the really hot days, people just leave the building and hang out in front of the hotel.

It's too unsafe to leave the room door open, even though it would feel cooler. The [new] building I live in now is so much safer and more comfortable.

Why some buildings in San Francisco have exterior shading and/or air-conditioning

Typically, the designers can advise and advocate for exterior shading, but the final decision is usually up to the developer.

It's up to the designers to make a persuasive argument for it. As for mechanical cooling, even though not often used in San Francisco, it's expensive to install in high-rises. But heat waves without appropriate cooling strategies can be expensive as well.

Engaging non-traditional stakeholders

There's a whole chain of people, including lawyers [representing building owners], who sign-off ensuring that buildings are habitable for occupants.

If they are not livable due to mold or heat, the lawyers can be held liable. We found reaching out to a small group of real estate attorneys bolstered our case to ensure homes were properly built so they, and their clients, wouldn't be held liable years later. This was one upstream approach to ensuring there was an added element of protection for future occupants.

Using multiple information channels

The only way to get developers to move from "patch and run" approaches to building good homes is to use the media.

We used a national campaign and supported an investigative series on defective new homes on national TV. Developers and realtors are extremely powerful and don't want this information out there.

We used this data to triangulate our literature review findings and confirm the need for a multi-stakeholder, collective impact approach to addressing overheated buildings. The mechanical engineers and building designers helped inform some of our building design solutions (see Figure 10: Solutions to building overheat).

UNDERSTANDING OCCUPANT EXPERIENCES USING SOCIAL MEDIA

Using information provided from the SFDPH Beacon building response letter[23] we knew hazardous conditions existed in one building. We used San Francisco's 311 complaint log data (general government services hotline) obtained from DataSF[24] and browsed San Francisco Department of Building Inspection's (SFDBI) on-line complaint inquiry system to look for cases of overheated buildings. We only found the Beacon complaint on SFDBI's complaint inquiry system relating to overheated buildings. These results are not surprising given that the hottest periods when overheating is likely occurs for only a brief period from late-September to early-October. A standard definition or index for an overheated apartment does not exist, and thus enforcement is difficult.[25] Also, people typically complain to a city agency because they want the city to play a role in addressing the cause of the complaint. Citizens may view overheated buildings as an issue to be taken up primarily with their building manager, not the city.

Social media sites like Yelp use user-generated content to inform other users about their experiences with service providers like restaurants, bars, retailers, etc. While we found limited data on overheating experiences using 311 and SFDBI data, over 30 users reported experiences of occupant overheat on Yelp and Apartment Ratings.

We applied basic standards to data collection and analysis for our social media sources adapting ASHRAE's (formerly the American Society of Heating, Refrigerating and Air Conditioning Engineers and one of the leading professional organizations concerned with overheat) definition of thermal comfort—"the condition of the mind that expresses satisfaction with the thermal environment." Instead, we capture instances where people did not express satisfaction with the thermal environment. Since thermal discomfort is a subjective evaluation, two team members separately read the comment and included the comment as a complaint using the following criteria:

- Occupant indicates s/he is too warm or too hot inside the residence based on context provided in the comment (required). For example, we did not include complaints about an overheated gym or lobby in the building.
- Occupant indicates length of stay in the building (optional).

A review of personal occupant experiences demonstrates thermal discomfort in multiple modern building sites, even in a cool climate like San Francisco. Using social media gives us a unique, and in some cases a more intimate, snapshot of overheating buildings and how people manage the problem.

WHAT IS OVERHEATING?

Overheating is the accumulation of heat in a building to the extent that the occupant feels too hot or warm.[26] Feeling too hot or warm may be based on a number of building environmental factors (e.g., air temperature, heat that radiates from objects, air velocity, humidity) and personal factors (e.g., clothing, work rate/metabolic heat), but is ultimately based on an occupant's opinion.[27] Traditional thermal comfort standards aim to ensure that at least 80% of occupants are satisfied with the thermal environment.[28] Still, ASHRAE is concerned that achieving optimal comfort in buildings may be compromised by climate change and other related factors.[29]

Northpoint @ 2211 Stockton St., SF

I've lived at Northpoint Apartments for almost a year now, and I hate it. I live on the ground floor (1st floor) facing the Street, and it's bad. There's no aircon whatsoever. My apartment is constantly overheated, and I have to open the patio door to get some air, and there's the noise again.

(Oct 2002) Source: Apartment Ratings

WHAT ARE THE POTENTIAL ENVIRONMENTAL AND SOCIAL DRIVERS OF OVERHEATED BUILDINGS?

A number of environmental and demographic trends remind us of the urgency and importance of addressing overheating issues in San Francisco:

- **Climate change:** Extreme heat events are associated with increased mortality (see Table 2: Selected extreme heat events and mortality since 1993).[30] Climate modeling experts anticipate that the number of extreme heat days, or days that exceed the Bay Area region's 90th percentile average temperature, will dramatically increase.[31] They anticipate "an average 12 extreme heat days per year in San Francisco…20 such days annually through 2035, between 32 and 46 extreme heat days annually by mid-century and 70 to 94 days by the end of the century."[32] A more recent model estimates 39 extreme heat days by 2050 and 126 by 2099.[33] These extreme heat days will likely contribute to warmer buildings.
- **Climate variability:** "Weather variability is a key factor, which is why more people die in Toronto than in Phoenix—people aren't used to intense heat waves that rarely occur, but when they do, they create havoc… different cities have different profiles, too, and lifestyle and architectural issues also contribute; the brick homes in Philadelphia are less conducive to helping people through the heat than the airier homes in the South."[34] Also, as people acclimate to warmer weather every summer in a city, bodies are more resilient. Hot weather in early October may not be as dangerous as a hot period in early June.[35] This research suggests San Franciscans are at risk for heat-related exposures since many are not used to regular heat waves and the population will have challenges acclimating to hotter temperatures that may come earlier in the summer.[36]

Table 2: Selected extreme heat events and mortality since 1993[37]

Extreme Heat incident, year	Deaths
Philadelphia heat wave, 1993	118
Chicago heat wave, 1995	739
European heat wave, 2003	70,000
California heat wave, 2006	650
Russian heat wave, 2010	11,000-50,000

- **Urban heat island:** San Francisco, with large numbers of buildings, paved areas, and minimal tree canopies, is an urban heat island, where temperatures may be 5 to 8°F degrees warmer than surrounding rural areas. Buildings that accumulate heat during the day begin to slowly release heat at night leading to greater temperature differences between urban and rural areas, characterized by more permeable and fewer paved areas. Consecutive extreme heat days can compromise a building's night-purge ventilation ("flushing") which is essential to removing heat from a building.[38]

- **Senior "swell":** Physiologically, seniors are more vulnerable to heat-related morbidity and mortality. One in five are aged 60 plus,[39] which means San Francisco has a disproportionately higher percentage of seniors than the regional, state, and national average. Seniors may also be socially isolated, which makes them less likely to recognize heat-related symptoms and less willing to engage others for help.[40] This is especially true for San Francisco's aged population living in residential hotels.
- **Additional factors affecting heat vulnerability:** San Francisco, and neighboring Alameda County, contains eight of the 13 census tracts most vulnerable to heat in the entire United States.[41] Some factors included in the study relate to basic demographics, land cover, diabetes prevalence, and air-conditioner access. Roughly 11% of housing units in the San Francisco region have access to air-conditioning.[42] In a recent study, ownership of air-conditioning reduced mortality by 80% when temperatures exceeded 90°F.[43]

WHAT ARE THE GAPS IN REGULATING OVERHEATED BUILDINGS?

Residential buildings or housing codes in California do not yet provide an enforceable standard for maximum indoor temperatures. However, professional standards issued by ASHRAE dictate that the maximum indoor temperature should not be greater that 78-82°F in the summer depending on humidity.[44] The National Oceanic and Atmospheric Agency advises that a heat index (combines temperature and humidity) above 80°F can result in fatigue and heat cramps whereas a heat index of 90°F can result in heat cramps and heat exhaustion. The American Conference of Governmental Industrial Hygienists recommends a workplace standard for taking action when the wet bulb globe temperature (WGBT) is greater than 80°F and limiting exposure when the WBGT is 86°F. These latter standards, which are applicable to healthy workers and not other populations, are intended to be protective against a rise in body temperature of 1.8°F and take into account levels of physical activity, humidity, and clothing.

In San Francisco and other major cities, a gap exists for ensuring adequate compensatory cooling requirements for dwelling units. SFDBI enforces minimum heating requirements for dwelling units under the housing code. However, the purpose of the housing code is to "provide for the maintenance of the minimum requirements for the protection of life, limb, health, property, safety and welfare of the general public and the owners and occupants of residential buildings in San Francisco."[45] This objective should encompass the range of thermal comfort to include minimum heating and cooling requirements, yet complement energy efficiency building codes and standards.

In San Francisco, minimum heat requirements in rooms entail "maintaining a room temperature of 70 degrees Fahrenheit...for 11 hours between the hours of 6:00 a.m. and 12:00 midnight."[46] Based on an analysis of 311 call data, heating, rather than overheating, is the primary concern of San Francisco residents. This is understandable as cooler days, where heating may be needed, are the majority relative to the brief warmer periods in San Francisco.

New York City, under their city housing maintenance code, requires certain indoor temperatures based on the outdoor temperature, time of day, and time of year (see Figure 3: New York City's minimum indoor temperature requirements). That the code mandates certain minimum temperatures for the cooler periods of the year, October until May, indicates a focus on the minimum requirements for ensuring heating for tenants.

Figure 3: New York City's minimum indoor temperature requirements[47]

HOW DOES HEAT IMPACT HEALTH?

1. Physiological responses to heat

The human body has a core temperature between 97°F and 100°F and can temporarily withstand up to 100°F and 102°F.[48,49,50] Most people begin to feel warm when the room is at 77°F, hot at 82°F, and may experience heat stress at 95°F.[51] The human body's ability to maintain heat loss and gain is called thermoregulation. When the surrounding air temperature is higher than the occupant's temperature, the body's heat loss ability may be impaired and heat gain occurs within the body (see Figure 4: Physiological reactions to heat).

Infinity @ 160 Folsom St., SF

I am at the Infinity and have both westward and eastward facing windows in the midrise/ tree-top building and can definitely vouch on the heating effect on a sunny afternoon (even w/sunshades down). Perhaps because I'm on a lower floor (view more of the courtyard than anything else) that even opening up the windows on both sides doesn't do much to vent although opening up the door to the hallway does a little bit.

(Jan 2013) Source: Yelp SF

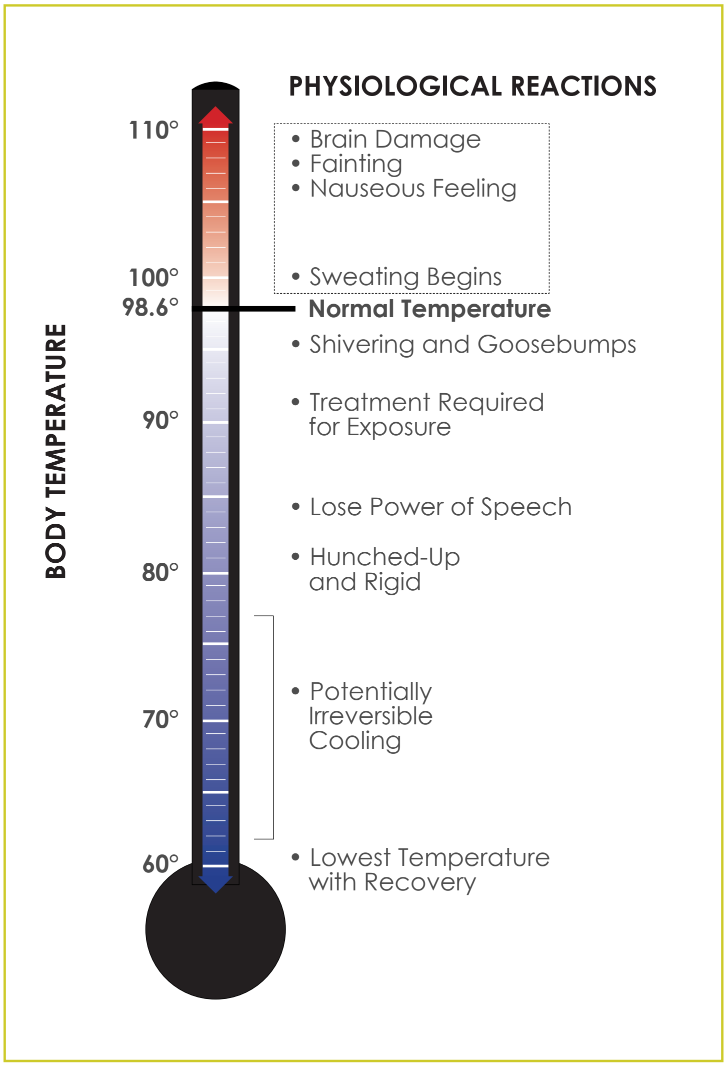


Figure 4: Physiological reactions to heat

The body's main physiological response to heat gain is to sweat and aid in cooling. Widening of the blood vessels, increasing the heart rate, and respiration through exhalation are other mechanisms for regulating heat loss.

Room temperature, humidity, air movement, radiant energy, clothing, and heating/cooling machines can influence the body's susceptibility to heat gain. Behavioral, social, and cultural factors can also impact how a person responds to heat gain. Human adaptive capacity to heat gain over the course of a summer is indicated by a greater risk of morbidity and mortality being experienced in the beginning not the end of summer. However, most of the evidence suggests a body's ability to adapt to heat usually takes years to develop.[52] Adaptation to a warming climate will occur, but not at the speed of warming temperatures.[53]

2. Health impacts of heat

Increased temperatures are natural hazards that can affect human health (Figure 5: Pathway diagram for health impacts). Dehydration, heat cramps, fainting, heat rash, heat exhaustion, and possibly fatal heat stroke are all classified as heat illnesses.[54] Excessive heat exposure may reduce productivity, efficiency, and mental concentration.[55]

Figure 5: Pathway diagram for health impacts

Contributing heat gain factors in buildings	Health Impacts	Proposed Solutions (TBD by collaborators)
• Internal heat gain - thermal comfort indicated by: - air temperature - heat that radiates from objects - air velocity - humidity • External heat gain • Insufficient window glazing • Improper building orientation • Inadequate ventilation • High exterior temperature	• Dehydration • Heat cramps • Fainting • Heat rash • Heat exhaustion • Heat stroke • Impaired mental concentration	• Regulatory approach • Behavior change approach • Design approach - Insulated walls - Windows - Natural ventilation - Mechanical ventilation - Ceiling fans - Cools roofs - Exterior shading

Paramount @ 680 Mission St., SF

NO air conditioning! in a "luxury" apartment building! You have to be kidding me. Depending on what side of the building you are on is when the apartment turns into a cooker when the sun is full on coming into the windows even with all the shades down and fans blowing. The nonsense about SF weather is just that because of the micro climates - in this building it is often sunny and it gets boiling hot in the apartments. Ours had the windows locked closed by the owner. I was naive, because for $7k plus a month, I didn't even think of asking whether there would be aircon - what 30-40 story luxury buildings don't! And of course you can't fit your own aircon to the windows because it would be dangerous to have a DIY aircon unit sticking out 30 stories up.

The ventilation is horrible. Even on cloudy days whatever you do, do not cook, because the smell will be with you for days, because you can't ventilate the apartment.

(Jul 2012) Source: Yelp SF

3. Sub-populations are more at-risk

The elderly, infants and children (up to age 4), obese, those with chronic illness, and those on specific medications are at increased risk for heat illness. The elderly are likely to have higher rates of chronic illness than the general population, take more types of medications, and have other "underlying factors that compound their risk to indoor heat" (see Table 3: Vulnerabilities to heat stress). These factors predispose seniors to an "accelerated rise" in body temperatures and greater susceptibility to dehydration which can result in heat illness. San Francisco's one in five senior population that continues to age, could place a high level of strain on the health system during extreme heat events.

683 Brannan St. Lofts @ 683 Brannan St., SF

The worst living situation I've ever had. First of all, these apartments are clearly built over the gates of hell as the apartment is so hot all the time -- even in the dead of winter it was hot! Secondly, even with multi-paned windows, the noise level from the street is unbearable…and you have to have the windows open since it is so hot!

(May 2009) Source: Yelp SF

Table 3: Vulnerabilities to heat stress[56]

Pre-existing health conditions	Extremes of age
Obesity	Older people (particularly over 65 years)
Poor existing health	Children and infants
Pre-existing dehydration	
Cardiovascular conditions	**Inability to adapt behaviours**
Respiratory conditions	Alzheimers
Chronic fatigue	Confinement to bed
Sleep deprivation	Disabilities
Low fitness or physical disabilities	Those at extremes of age
Uncontrolled diabetes	
Medications affecting thermoregulation	**Environment**
Long term high level exercise	Residing in upper floors of buildings
Gastrointestinal conditions	South facing flats
Psychiatric illness	Lack of adequate ventilation in home or air conditioning
Hyper/hypotension	Living alone
Renal complications	Socially isolated
Previous heatstroke	Lack of acclimatisation
Alcohol and/or drug abuse	Urban dwelling
Certain neurological disorders	Care home residents
Pre-existing electrolyte imbalances	
Peripheral vascular disease	
Eating disorders	
Dermatological disease or damage	
Fever	

Children have less physiological ability than adults to regulate their temperature and control their local environment (e.g., adjust room temperature, open windows, etc.). Some researchers have suggested a connection between sudden infant death syndrome and core body temperature but the research is inconclusive.[57]

Specific medications can exacerbate dehydration, decrease sweat production, increase heat production through physical activity, and reduce blood flow to the skin.[58] Drug efficacy and toxicity may also become issues for residents already dehydrated who have changed blood volumes.[59]

WHAT IS THE CONNECTION BETWEEN OVERHEATED BUILDINGS, VULNERABILITY, AND EQUITY?

Individual and community heat vulnerability is also determined by the ability to "anticipate, cope with, resist, and recover from the impact of major weather events."[60] The San Francisco Health Vulnerability Index (see Figure 6: Heat vulnerability map by the San Francisco Department of Public Health) shows that within the neighborhoods, and among individuals in the neighborhoods, some people are more at-risk for heat-related illness.[61]

These vulnerable groups are likely to spend more time indoors than the general population, thereby increasing exposure to overheated buildings. These groups are also more likely to live in sub-standard housing with inadequate building design elements, limiting protections against thermal comfort issues. Access to fewer financial resources, social networks, and air-conditioning could lead to a disproportionately higher extreme heat impacts on vulnerable communities than the general population. "Without proactive policies to address these equity concerns, climate change will likely reinforce and amplify current as well as future socioeconomic disparities leaving low-income, minority, and politically marginalized groups with fewer economic opportunities and more environmental and health burdens."[62]

Avalon at Mission Bay North @ 255 King St., SF

The places that face west are greenhouses and saunas. After living there for about a month, we realized that we had made a big mistake. The apartments are not ventilated at all and the blinds do not keep the sun out. The overall construction is cheap and flimsy. On a winter day, the temperature of the apartment would get very hot and stay hot.

(Feb 2008) Source: Yelp SF

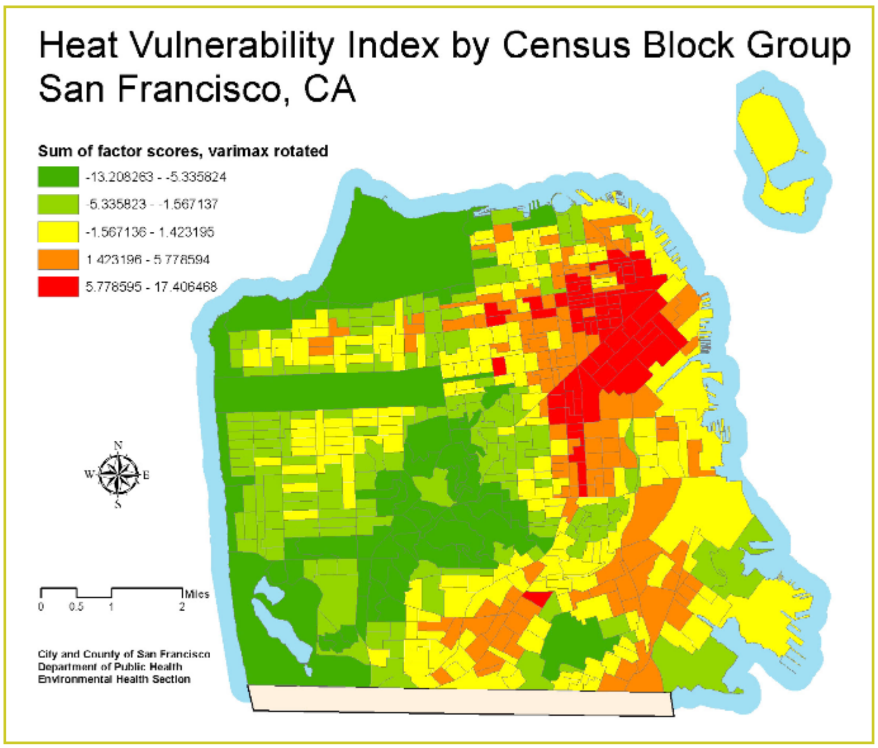


Figure 6: Heat vulnerability map by the San Francisco Department of Public Health

WHAT BUILDING TRENDS CONTRIBUTE TO WARMER HOME ENVIRONMENTS?

People spend between 70-90% of their time indoors, mostly at home.[63] Few documented examples exist of overheated buildings in San Francisco,[64] though anecdotes are widely available of varying building types from modern high-rise condominiums to overly "tight" retrofitted homes.[65]

Tighter building envelopes with higher thermal insulation and larger double-glazed window surface areas adhere to more energy efficient standards that can contribute to warmer units, especially when adequate cooling design elements do not exist. Dwellings with a south-western window façade can experience heat gain and become like "ovens" during warmer periods (see user experiences).

Buildings in urban settings are more susceptible to heat gain than those in rural settings. Several exterior building factors associated with heat illness are listed below. Less obvious exterior building factors which may compromise a building's ability to reduce heat gain are included in the next section ("How do buildings overheat?").

Edgewater Luxury Apartment Homes @ 355 Berry St., SF
I toured the property when the weather was cool and as every place in SF, they said you wouldn't need air conditioning when it gets warm. THIS IS A LIE AND BEWARE!!! My place on the second floor was the hottest 1 year I can remember spending in any place, and I lived in Atlanta before this. When it was 75 outside, it was 85 or higher inside. I can honestly say that if you are bothered at all by sweating 24/7, this reason alone is cause to look somewhere else. If they try to offer you a portable air conditioner, it helps some, but raises your power bill by 3-4 times if you use it.
(Dec 2008) Source: Yelp SF

- The highest buildings were estimated to have a 50% increase in extreme heat-related mortality compared to smaller buildings less than 14 feet in height in a London-based study.[66]
- A study by the same lead author showed homes in five-story buildings were +2.5°F warmer than smaller buildings among homes built between 1914-1945.[67]
- Living on the top floor of a building, duration of sunlight directly entering a bedroom, living alone, living in a unit with fewer rooms, and having a flat roof were associated with heat deaths.[68,69] 19% of San Francisco seniors live alone compared with the nationwide average of 10%.[70]

Bayside Village @ 3 Bayside Village Pl., SF
I had a studio on the 3rd floor overlooking an internal pool and facing the sun. The place got SUPER hot as sun bounced off the pool and concrete. I had to get TWO portable AC units to keep my unit at a reasonable temp. Otherwise it would get literally 90 degrees in the summer. This place really should have AC.
(Jul 2010) Source: Yelp SF

HOW DO BUILDINGS OVERHEAT?

Buildings experience heat gain through two pathways—internal and external heat gain—which may result from single or multiple compounding causes. We explain overheating causes and some environmental factors specific to urban environments.

Sunlight and high exterior temperatures can cause external heat gain. Highly insulated building envelopes can minimize warmed air from escaping the home during the winter months. As homes experience more extreme heat days, heat enters through windows and can warm interior surfaces and objects (see Figure 7: Internal heat gain sources). The double-glazed windows, sometimes operable up to only 6 inches, may prevent unwanted heat from escaping during warmer periods. Opening windows can be problematic in San Francisco if exterior temperatures are warmer than the interior and if building units face high air pollution or noise areas.

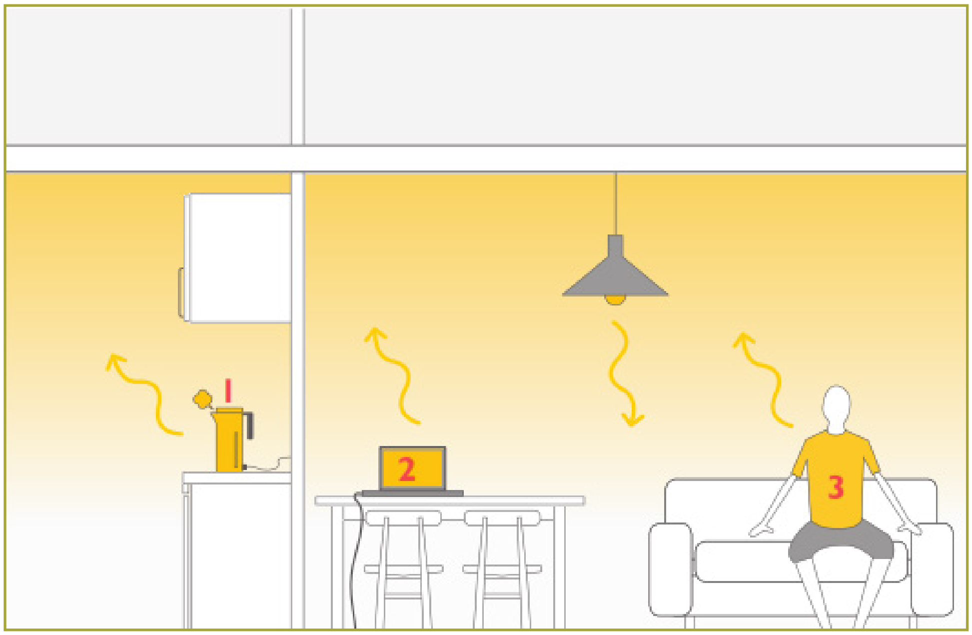


Figure 7: Internal heat gain sources
Internal heat gain sources include cooking (1), operating appliances (2), and occupants (3). Lighting can also be a source of heat gain.[71]

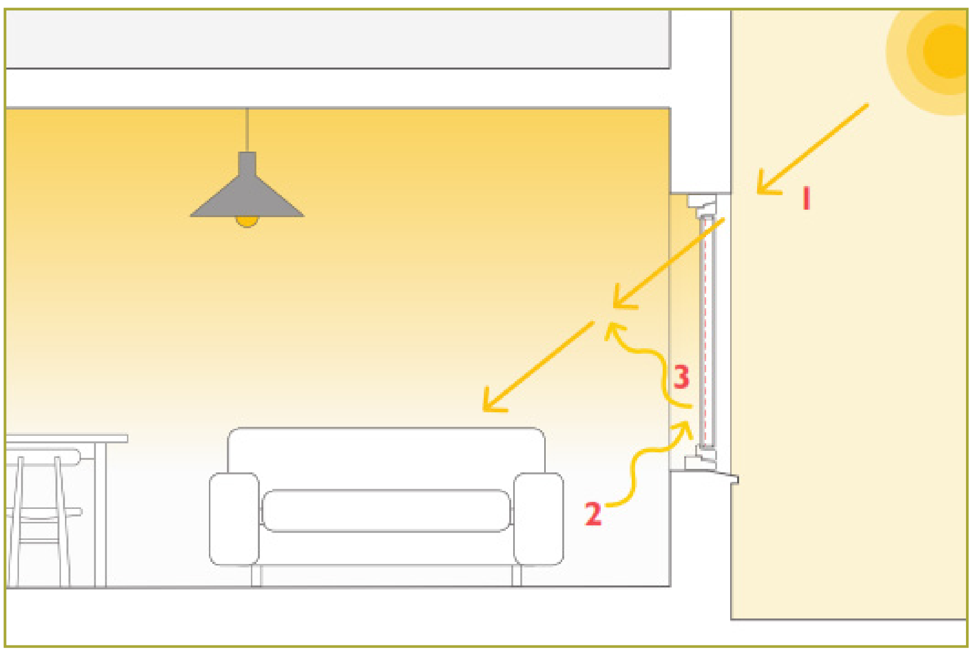


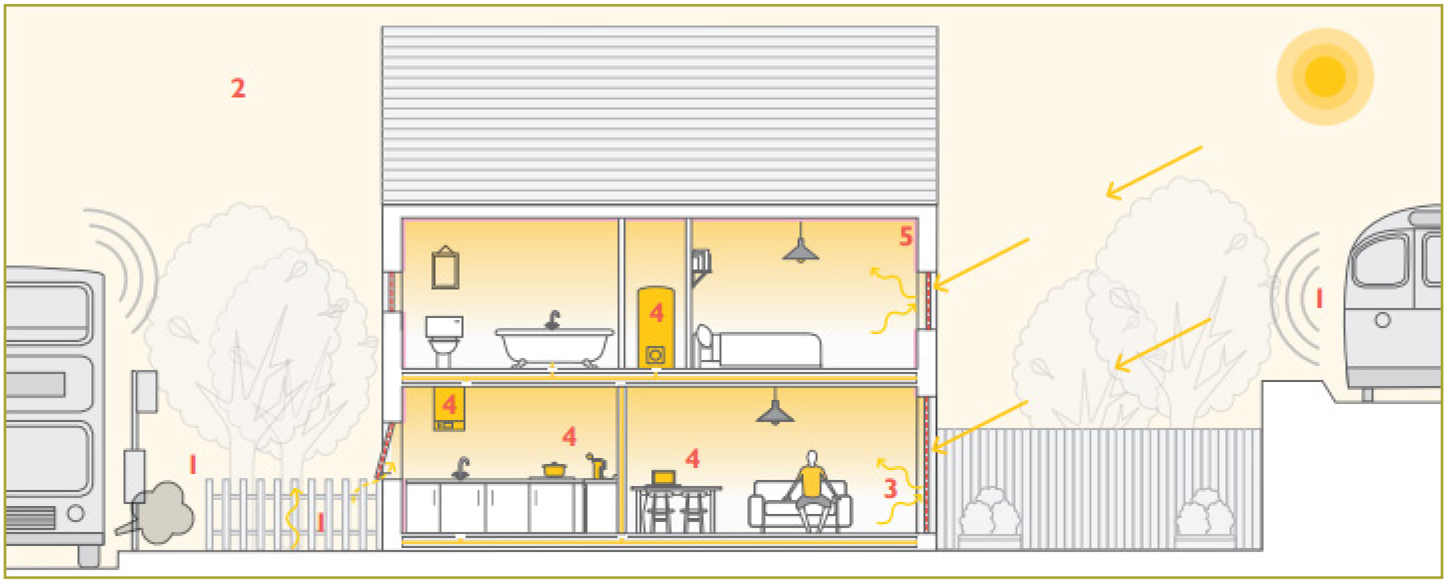
Figure 8: External heat gain sources
External heat gain sources and causes include intrusion of solar gain into interior spaces (1), warmed furniture giving off heat at night (2), and internal heat gains remaining trapped due to a tight building envelope (3).[72]

The impact on internal heat gain is more pronounced on newer, tighter homes than most of San Francisco's older housing stock. The trend to design smaller spaces (e.g., micro-apartments in South of Market[73]) may amplify this heat gain effect. The primary causes of internal heat gain are lighting, appliances, occupants, and building infrastructure elements. TVs, laptops, drying machines, even when not in use, can emit heat. During San Francisco's typically foggier and colder months, residents welcome these internal heat gains which can supplement traditional space heating. With the vast majority of San Francisco residents not having access to air-conditioning, compounding internal heat gains may be problematic during extreme heat days.

WHAT ARE THE INTER-RELATED FACTORS LEADING TO OVERHEATED BUILDINGS?

How buildings experience heat gain is dependent on a host of inter-related and complex factors (see Figure 9: Cumulative effects of heat gain). Exterior building factors may increase the risk of overheating. Some site-specific factors are not easily changeable, such as the orientation of a building, but should be considered in any strategy to minimize future overheating.

Figure 9: Cumulative effects of heat gain[74]



- The building site and orientation is the primary determinant of how much direct sunlight is received. For large-scale condominium projects, different units within the building may experience highly variable sun exposures. A south-west facing unit will likely receive much more direct sun exposure in the late afternoon when outdoor temperatures are highest, than a person living on the north side of the complex. This makes higher, south-west facing units much more vulnerable to heat gain, unless additional design elements are implemented to minimize heat gain.[75]
- Concrete and brick streetscapes can absorb heat throughout the day and slowly emit heat at night to surrounding apartments, contributing to the urban heat island effect. If a building is near a mixed-use facility with restaurants or supermarkets, refrigeration mechanical equipment might be constantly operational and emitting heat. Cooler outdoor temperatures are essential for an effective night-purging ventilation strategy.
- A number of new San Francisco high-rises are built with only passive cooling strategies and mechanical heating. These units have limited window operability and may have limited potential for adequate ventilation. These units may be at risk for overheating.
- The thermal mass, or how the building's materials respond to temperature fluctuations, may be another contributing factor to overheated buildings. As objects and building walls and floors get warmed through windows, they then emit heat directly into the home at night. Communal heating systems and pipes carrying hot water may also be another source of unwanted heat gain to building walls. Without adequate ventilation, nighttime heat-purging may be compromised.
- A building's proximity to high traffic and high noise areas could lead to an occupant's unwillingness to open windows and naturally ventilate, a primary strategy for reducing heat gain. Exposure to traffic and resulting air and noise pollution can cause adverse health effects.[76,77]

LIMITATIONS

While minimal heat stress-related hospitalization data in San Francisco and lack of exposure response functions for overheated buildings posed initial barriers, the integration of HIA and design thinking encouraged "outside-the-box" thinking.

We assume that the social media data obtained were relatively accurate in obtaining a "sketch" of the how occupants manage living in overheated buildings. However, this small sample of occupant reviews is biased towards social media users and those who can afford to rent and own in high-rise, modern condominiums in San Francisco. Collecting viewpoints of seniors and low-incomes residents, many of whom are more vulnerable to the health impacts of overheated buildings, could provide valuable comparisons with those living in high-rises. These snapshots did not provide any information as to the distribution of persons negatively affected by overheated buildings in San Francisco or severity of health impact. Still, based on the literature, we have a high level of confidence in assessing how heat impacts health and how buildings overheat. Our interviews with experts generally corroborate our findings in the literature review (assessment).

In order to contribute to our original research questions, it was necessary to assume some reasonable uniform conditions and causes among diverse building types and households in San Francisco. We do not account for indoor and individual factors which can contribute to overheating such as cooking, clothing, and physical activity.

Recommendations

Heat adversely impacts health. As a result of climate change, San Francisco's historically cool climate is becoming warmer. Radical collaboration between agencies to address the growing challenge of overheated buildings may:

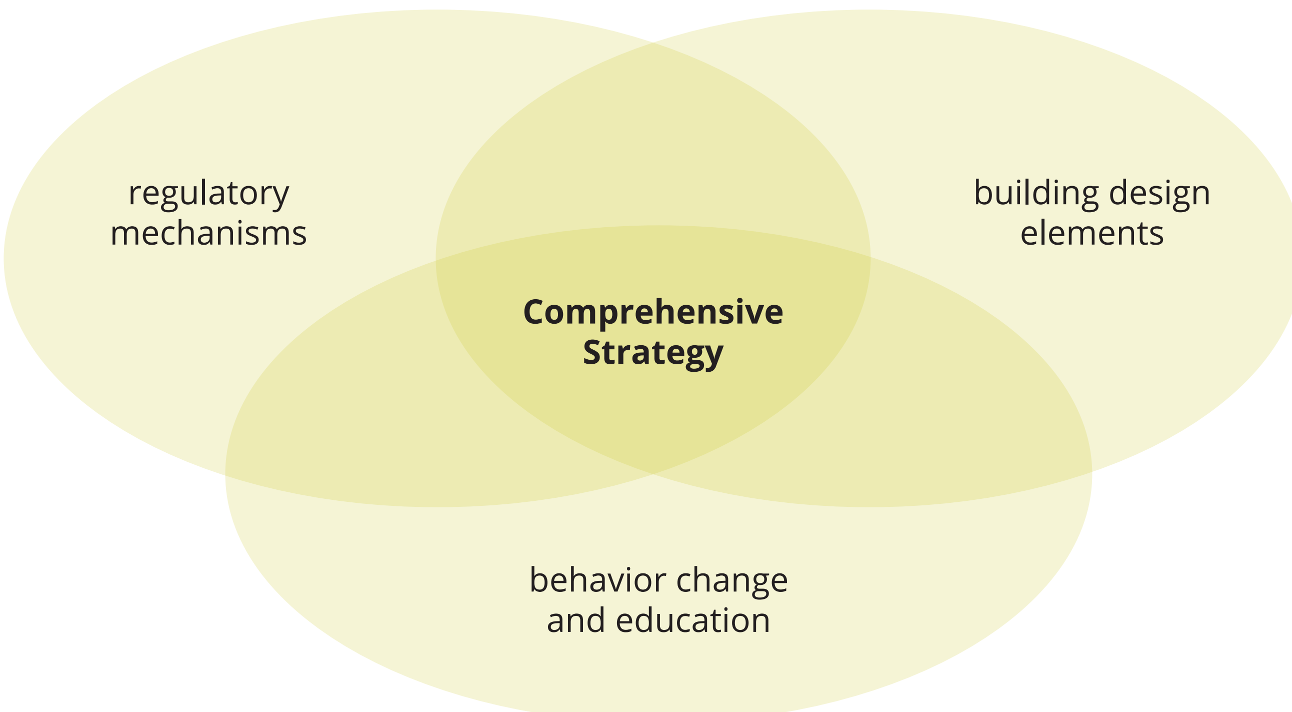
- Reduce risks to heat-related illness
- Cut down on greenhouse gas emissions
- Minimize costs from air-conditioner usage.

A COMPREHENSIVE STRATEGY

Based on our initial findings, we propose a three-part comprehensive strategy based on:

- Building design solutions
- Regulatory/code-based solutions and enforcement
- Behavior change solutions

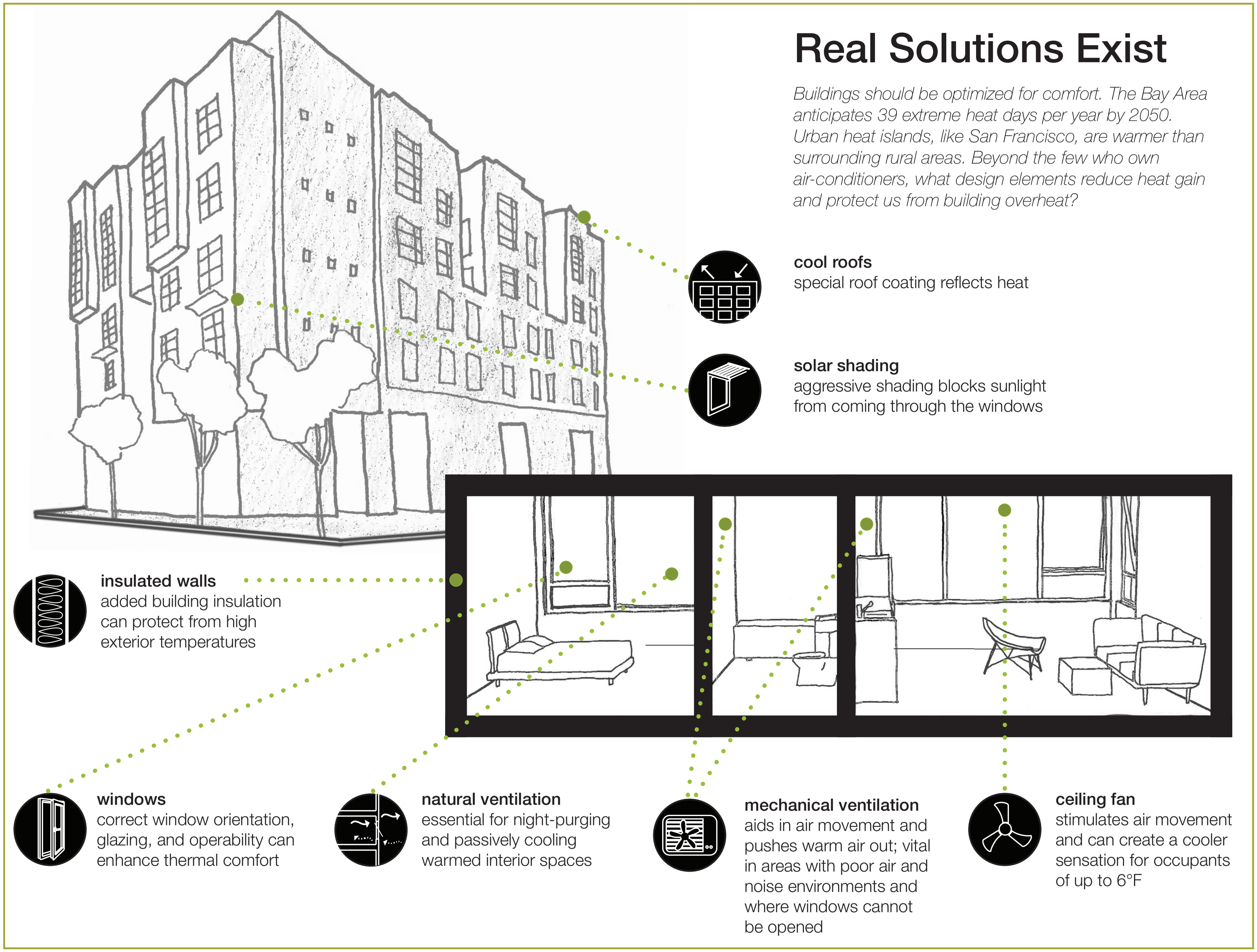
Identifying strategies and solutions fundamentally require the collective input of several stakeholders on such a complex issue. As a suggested starting point, we provide a few illustrative building design solutions.



BUILDING DESIGN SOLUTIONS

Practical building design solutions exist to ensure homes are optimized for comfort and minimize energy usage. We look at a few building design solutions to address the challenge of our warming communities (see Figure 10: Solutions of building overheat). Building design solutions are one component of a multi-pronged strategy to reduce the health impacts of heat gain.

Figure 10: Solutions of building overheat



1. Purge ventilation

Purge ventilation can be implemented through having cross-ventilation that circulates air throughout the unit and “purges” the heat gained room with cooler air. The cooler air can come from mechanical air conditioning or cooler nighttime air. Applying a manual purge ventilation strategy requires windows to be opened during optimal times to remove heat.

2. Ceiling fans

The use of ceiling fans to stimulate air movement can create a cooler sensation of up to 6°F for occupants.[78,79] This design element can have an immediate impact on providing thermal comfort for residents who need a more immediate sensation of relief. Ceiling fans can also aid in pushing and purging warm air out of a unit experiencing heat gain. These fans can also address an occupant’s desire to control and “do something” during an extreme heat event. Further, ceiling fans are a cost-effective solution in cooling an apartment when compared with an air-conditioner.[80] However, fans (both wall-mounted and portable) contributed to excess sweating and dehydration when the room air temperature was 95°F or higher, a recent meta-analysis found.[81]

3. Windows

Windows are complicated design elements, especially in urban environments. Windows offer a range of indoor environmental quality benefits such as no-cost warmed or cooled air for thermal comfort, aesthetic benefits for occupants, adjustable ranges for thermal comfort, fresh air, and natural lighting. However, there are a number of possible negative aspects (see Figure 9: Cumulative effects of heat gain)—windows can be a primary source of heat gain and contribute to the intrusion of traffic noise and air pollution. Proper glazing, especially for those with the greatest amounts of exposure on the south-west side, is an opportunity to minimize heat gain. Operable windows should consider safety (infants may fall out of windows) and security elements (reducing opportunities for theft), and open in ways that facilitate night-purge ventilation and bring in cooled air.

4. Solar shading

Solar shading represents a tremendous opportunity to minimize heat gain and cooling air costs. Several examples exist of exterior shading design elements in San Francisco that both applied evidence[82] to inform design and won approval from an aesthetic perspective (see Figure 11: Exterior shading at 388 Fulton).

Figure 11: Exterior shading at 388 Fulton (rendering)[83]

San Francisco’s unique windy conditions, especially at higher floor levels, should be considered so that exterior shading devices are not at risk for being blown away or becoming structurally compromised.[84] There are a number of examples and opportunities for San Francisco builders to integrate exterior shading into their building plans and designs. The current mainstream practice of using interior shades to block solar heat gains is insufficient and inefficient when compared with exterior shading in a warming climate.

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[3] The implementation of air-conditioning as a public policy design solution should be carefully balanced with the financial and energy costs. While blackouts during extreme heat events are relatively rare in the US, residents could become highly vulnerable to heat stress by having an air-conditioner without a power supply. Furthermore, a growing number of home designers like Steve Badanes, an architecture professor, suggest relying wholly on incorporating passive cooling design strategies, where possible.

Conclusion

Climate change is the defining challenge of our generation. Overheated buildings and health is arguably the first act of many in the unfolding epic of climate and health. We all have a commitment to collaborate and facilitate deep, systems-based solutions that protect the health of San Franciscans and others in vulnerable coastal communities.

The purpose of this HIA was to bring attention to the health issues related to overheated buildings in a coastal community using San Francisco as a case study. The HIA serves as a starting point to support radical collaboration between HVAC engineers, community leaders, policy makers, health officials, building regulators, realtors, residents, and others. We hope this HIA contributes to the knowledge base that moves the issue of overheated buildings and health forward.

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