ENeRGY

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everywhere

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nowhere

Energy is an elusive concept. While being universally recognized it is rarely understood. We continually misinterpret our thermal interactions with the surroundings. We have curated interfaces that elucidate often overlooked aspects of energy – from the potentials of low exergy buildings to the misperceived heat transfer from surfaces around us – contextualized within a framework of energy opportunities that are literally everywhere, but nowhere to be seen. This exhibition reveals the manifestations of energy by unexpected means at three radically different scales: the human body, the building scale, and the urban scale. The various projects displayed explore the transfer of thermal energy which connects all three into an interdependent network of exchange.

ENERGY AND THE HUMAN BODY

The human body utilizes energy for you to move, think, and operate. It does so in constant thermodynamic exchange with its surroundings. As with any engine, your body cannot use energy at 100% efficiency. This is dictated by the second law of thermodynamics. The inefficiencies are manifested in the heat your body must dissipate to operate. Your body is therefore generally warmer than its surroundings, as can be viewed on a thermal camera.

Your comfort is the sensation of how easily your body is rejecting heat. Although it is always operating at the same temperature, your body must adjust to many thermal inputs. Air temperature is what we consider first in terms of comfort, but it is one of several factors that all have significant impacts. Along with air temperature, humidity, air speed, and radiation all play major roles in defining how easily your body can operate at its requisite temperature. Additionally, the varying clothing levels and metabolic rates can dramatically shift the perception of comfort and the desire for warmth or cool. Managing that desire has now become a central component of architecture and its heating and cooling infrastructures. Current techniques though, still only consider air temperature, and neglect the many other factors that can be influenced by design.

ENERGY & BUILDINGS

The vast majority of energy demand in buildings is used for maintaining thermal comfort. Thermal comfort is what demands the heat transfers driven by modern heating and cooling systems. But most will agree that thermal comfort is not readily achieved, even when nearly every building has automated heating and cooling systems.

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Buildings are the largest single sector of energy demand. In the US, 40% or primary energy is generated for buildings. Energy in buildings now has an importance that rivals that of the occupants and the architecture. This has led to a sentiment that energy systems complete with occupant needs or the architectural design process, and has resulted in architecture often sidestepping energy rather than engaging with it. But we argue and demonstrate that energy is not an independent concept to be dealt with only through technical engineered solutions. Energy is full of potential, both physically and literally. The understanding of both the physically measurable potential along with the architectural and human interactions that influence potential are necessary to successfully address the energy challenge in buildings.

The enormous primary energy demand of buildings results in buildings also being a significant greenhouse gas emissions source. Both in operation and construction there is a vast amount of latent potential found in the overlooked forms of energy, which can help mitigate negative environmental impacts. The form of energy being thermal or electrical may present similar absolute energy quantity, but there usability is dramatically different. Transforming high quality electricity into the tempering of room air is a huge loss of potential.

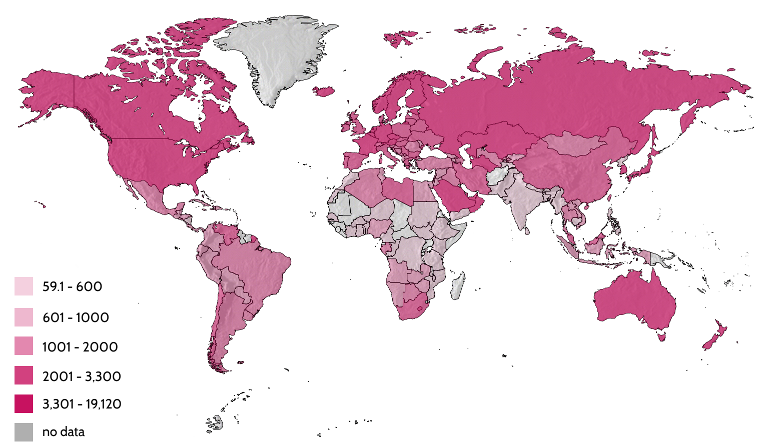
Heating and cooling are in fact relatively benign forms of energy, but when they are produced with electricity or high temperature boilers and furnaces a lot is wasted. This is recognized in the difference in temperatures needed to create these forms of energy, and is quantified by the concept of exergy that recognizes the added value of energy forms created from high temperatures or high-potential generation techniques.

ENERGY & THE URBAN ENVIRONMENT

Energy is in fact everywhere - its complex range of potentials is present at the urban, regional, and global scales. District energy systems can leverage common potentials to reduce the demand place on high quality energy resources. District heating and cooling systems have evolved over the past decades to match the waste sources of heat at the community scale with the demand for low temperature heating in buildings. For cooling, the ability to use the latent energy of evaporation to access moderate temperatures with much better cooling capacity has long been used to improve large system performance, but has rarely been considered for its application so smaller and residential systems, which would experience the same performance gains. Across cities, there are numerous sites where latent thermal energy from industry has potential for urban district heating and cooling.

Even at the scale of entire countries, places like Iceland and Denmark deliver heating and cooling hundreds of kilometers. Planners and designers can engage in those systems to align thermal resource supply and demand across regions.

Understanding the inherent changes in system capacity and the ability of thermal energy to be stored at the large regional scale can also have huge benefits to managing the inherent intermittency of renewable electricity sources like wind and solar. Understanding how the occupant's need for thermal energy can be delivered through a system that acts as an intermediate thermal sink matched to both the heat transfer most relevant to the user as well as to the locally available temperatures while at the same time requiring electrical inputs only when available on the grid is a way that energy's role can truly be considered everywhere while remaining nowhere to be seen.



GLOBAL ENERGY DEMAND

units: kgs of oil equivalent per annum

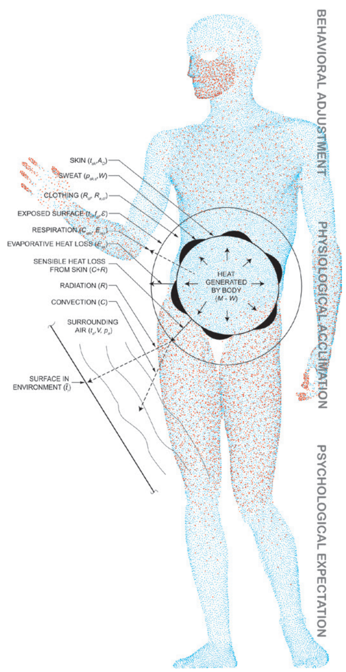
1

BODY BUILDING

andrew cruz

Comfort is an energetic and symbolic nexus between citizens and cities. Its definition simultaneously contains the thermal relationship between a body and its environment, and our individual identities as part of larger societies. Architects are professionally predisposed to see architecture as the primary context for comfort. However, shifting focus from the building to the body highlights how clothing–our personal architecture–shapes contemporary notions of comfort in ways that buildings cannot. The exhibition Personal Architecture examines how the comfort of clothing presents design opportunities for rethinking the relationships between the body, energy and architecture from the scale of the individual to the city.

The body's skin is a thermally active surface. Clothing mediates the microclimate between the skin and the surrounding environment to provide comfort. While building comfort standards typically considers only the insulation value of clothing (with the CLO unit) this exhibition examines a range textile technologies, and the different conditions they create at the skin: breathability, absorption, heat release, layering and stretchiness. Such features allow clothing to satisfy individual comfort preferences, and to adapt to varying climatic conditions. Instead of the fixed collective comfort conditions maintained within a building's envelope, clothing allows for varied personal comfort at the scale of the body. Such improved comfort can also result in improved energy efficiency as less demands are made of building HVAC systems. Personal Architecture links physiology and fashion, individual and collective, indoors and outdoors as the introductory exhibition in the Energy Pavilion.



THERMAL EFFUSIVITY

kiel moe

2

Even if they are the same temperature, a block of wood "feels" warmer than a block of steel or concrete. While seemingly a subjective experience, there is a quantifiable material property that explains this difference in sensation: thermal effusivity. Thermal effusivity is a measure of a material's ready ability to exchange heat with its milieu. When touch the steel, we transiently transfer more heat than when we touch the wood. This is the basis of our sensations of warmth and coolth. Because the sensation of heat transfer plays such an important role in the perception of human comfort, so does this material property.

But the implications of this property are much bigger than our localized, individual experience of a material. Even if two rooms are at the same operative temperature, a wood room will physically feel quite different from a concrete one. Or, to state it another way, the wood room could maintain the same level of comfort with less input exergy. This material property, in fact, could be the basis of a very different approach to human comfort, one deeply connected to the materials we use to build and to the physiology of our bodies.

Rather than temperature, our hands and other sensory organs sense relative rates of thermal exchange or flow across our body-boundary. So when we do touch architecture, the transient behavior of our skin and adjacent materials becomes very important. For example, in the handrail leading to the upper level of the exhibition, a series of high and low effusivity materials are designed to trigger varying sensations of warmth and coolth as your hand moves up and down the handrail. The specification of materials according to thermal effusivity yields not a range of thermal experiences even at the same temperature, but can also make a much cooler space feel warmer and vice versa. Thermal effusivity is way to quantitatively incorporate our qualitative sensations of materials and our thermal milieu.

HANDRAIL: Alex Timmer & Kiel Moe

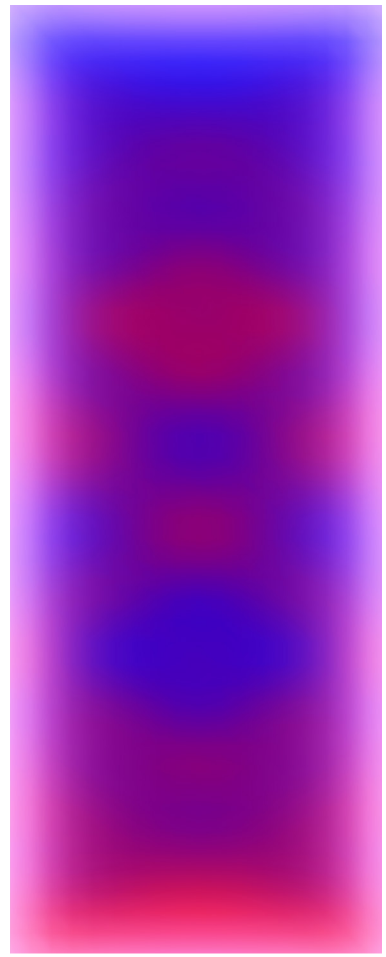
3 THERMALLY ALIVE SPACE

forrest meggers & dorit aviv

Our goal is to reconsider heat transfer as a fundamental part of space creation, by making visible the constant hidden exchange between our body and the architectural elements surrounding it. The human body is a complex thermal engine, with multiple sophisticated mechanisms for exchanging energy with its environment. The air temperature is just one of many factors that have significant physical impact on perceived comfort, yet thermostats measuring only air temperature control how buildings deliver thermal amenities, completely disengaging the architects opportunity to influence that interaction. It has been left to the engineering consultant to deliver a fixed solution to control the temperature of a room within a set of artificial criteria for temperature. These solutions aim at conditioning the space, not the occupant. They are also delivered as independent solutions that do not appreciate the many ways they impact the actual space of the room.

Here we exploit heat transfer by radiation, whereby higher or lower temperature surfaces exchange heat through blackbody radiation of electromagnetic waves. This exchange is independent of any interaction with the air temperature or movement. Like the sun, people are glowing masses emitting electromagnetic radiation, we just don't see in that wavelength. The radiation emitted from a warm person has more energy than surrounding lower temperature surfaces causing a net heat exchange independent of the exchange with the air in immediate contact. By placing someone in view of a surface that is ten degrees cooler than the air temperature, they will have the sensation that the space is cooler. If all surfaces around an occupant were dropped by ten degrees, research has shown they will predict the temperature of the room to be five degrees cooler than the actual air temperature. The same goes for warming the surfaces.

This means that the "undifferentiated" space, in fact becomes activated by walls, ceilings and other surfaces around it. The shape of the void determines the thermal interaction between its defining surfaces and the human beings occupying it. If the contemporary convention is that within the domain of the architect are the walls, the floors and the roof, and within domain of the mechanical engineer is thermal control by manipulation of air temperature, we divert here the ability and responsibility for thermal control back to the domain of the architect. The walls, floors, roofs, and windows, store heat or reflect it, emit it to people through radiation or convect it into the moving air. Architecture



Thermal map of installation space

is anything but silent in this game of energy exchange and surfaces are not real limits, but a layer of interface between themselves and their surrounding. The architectural elements that bound the void also constantly fill it and transform it.

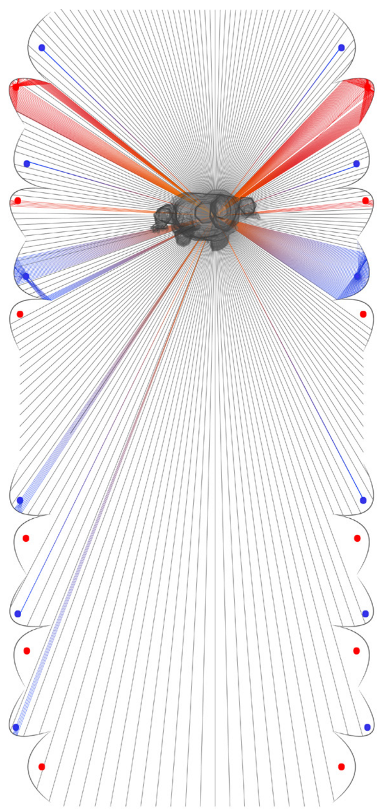
To make this invisible fullness visible, we create a darkened space where the sense which always overwhelms all others in architecture - vision - is subdued. Instead we construct the space out of hot and cold surfaces, heightening the thermal senses of the occupants. To achieve this, we install a highly discretized and controllable series of radiant heating and cooling surfaces. Asymmetric radiant fluxes guide people around the room. Thermal sensations become the differentiating element in a space that visually looks quite repetitive. In this space, the human beings are not disinterested observers as they move through the room. Movement and proximity of bodies and surfaces become triggers for action. As soon as a hot body comes into the view of a cold surface, they both must engage with one another in an exchange of energy.

Meanwhile infrared thermal cameras record the thermal interactions as they take place. As people move through the room, the cameras record the bodies' and surfaces' radiant

ENERGY & BUILDINGS

temperature. Radiative heat exchange is dependent on optics. In other words, surfaces will exchange heat in this manner only if they "see" each other. We make use of this fact to control the amount of cold or hot sensations that visitors experience throughout the room. Just like an op-art installation, where different colors are revealed as the position of a person changes in space, so would the amount of radiation change in relation to a person's position in the room. Infrared camera projections will make this hidden play visible to the human eye.

Radiant heating and cooling systems leverage the ability to shift thermal perception, while also operating more efficiently with system temperatures much closer to room air. These systems can integrate with the architecture to activate surfaces – typically ceilings or floors – creating an alternative experience of thermal comfort. Thanks to the larger surface area of heat exchange into the room, the system can transfer heat into the room with much lower temperatures than in an air-based heating system, or vise-versa for cooling with much higher temperatures. This greatly improves the performance of the system as these temperatures are much easier for the system to deliver, so even if two buildings have the exact same shell creating the same heat losses

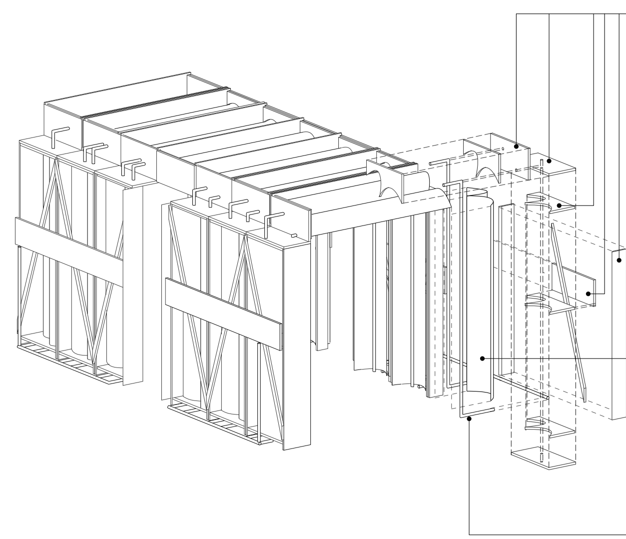


Body mean radiant temperature at a specific point in space based on the reflections of infrared radiation from the reflective surfaces.

and gains, that heat can be compensated by the system with much less effort if it is done so at less extreme temperatures.

Performance is a second critical aspect of the exhibition, revealing the concept of exergy and the inherent low-exergy nature of building conditioning. Radiant heating and cooling can require the same quantity of heating or cooling demand, but the thermal potential to achieve that quantity is lower as the temperatures are less extreme. This added efficiency is shown by displaying the performance of an actual heat pump and chiller as they operate moving heat at different temperature levels to supply the heating and cooling, which will be linked to the operation of the hot and cold surfaces and space.

ENERGY & BUILDINGS



CREATING CLIMATE

kipp bradford

Heating and cooling are essential elements of modern life. The thermal environment determines our comfort and productivity–and sometimes even our ability to survive in a space. However, as vital as heating and cooling are, these systems are never part of our building aesthetic. They are designed to be out of sight and therefore out of mind. We take thermal systems for granted, only ever thinking about them when they don't work. Here, we subvert this norm by showing off the technology system and revealing the magic that we all depend on.

Modern life requires readily available cooling, but cooling is a contradiction: everything we do to make cold ultimately makes more heat. This is the reality of physics. It is not possible to conjure up cold like we can conjure heat from a flame or friction, because cold is not the opposite of heat. Rather, it is the absence of heat–and heat will flow to where it is cooler. Thus to cool a system, we must transport heat against its natural flow. This transport requires work, and work requires energy. The flow of energy and the technology system that generates it deserves to be seen and understood, which is why we're showcasing it here. The technology, the heat pump, is often listed as one of the most important inventions of humanity. Relentlessly compressing and condensing gas, then evaporating liquid to remove heat against its natural flow, heat pumps are so integrated into our lives that we often ignore the value of this technology and take it for granted. The effort required to maintain a controlled, comfortable thermal environment means that heating and cooling represent the majority of the energy flow in and around buildings. It should therefore also command a significant portion of our attention.

A NEW TYPE OF VENTILATION

salmaan craig & forrest meggers

Moving air is inherently complex. The flows are almost universally turbulent in buildings, and the exchange of energy is dependent on both the air temperature, and its velocity. Supplying adequate air has driven much of the technological evolution of mechanical systems in buildings over the last century. Generally the complex dynamics of air have been overcome with brute force rather than elegant designs. Natural ventilation is commonly used to passively ventilate buildings. One of the major challenges of natural ventilation is the unpredictable frequency, direction, and strength of the wind. Buildings can often receive enough fresh air exchange through their shells, but for cool comfort a certain level of breeze is necessary. In the last decade, progress has been made in understanding a more reliable driving force – buoyancy. Buoyancy isn't powered by the wind. It' s powered by the waste heat from occupants, computers and other internal heat gains.

Hot air rises. We can design our buildings to exploit this. Heated by occupants and computers, the interior air rises naturally up a chimney that connects all the floors of an office building. As it escapes at the top, fresh air is pulled in from the windows and across the floor plates. With buoyancy ventilation, the fresh air is sucked in from the sides–by the warm air column rising up the chimney. On a hot day, when the occupancy is high, there may not be enough wind to flush out the interior. But buoyancy ventilation is different: as the occupancy increases so does the driving force. In other words, buoyancy is a force you can engineer. By design, we can reliably sustain a 'breeze' in the absence of wind.
How does one know how to size the chimney and the windows? If the openings are incorrectly sized, there will not be enough air flow, and the interior will overheat. This used to be a difficult problem, especially for multistory buildings. But new research has provided new insights. We now have simple mathematical models that retain the most important physics. Now design teams can easily decide if buoyancy ventilation is feasible, early on in the design process.

We have constructed a two buoyancy ventilation stacks to show how adding heat can drive air upward and adding cool can drive air downward. This heat and cold are simply the residual energy from our heat pump installation and could represent any variety of sources available in the built environment. You can observe and feel the free movement of the air, that although seemingly complex is now coaxed, not forced, into performing the ventilation and human conditioning we need without additional energy input.

6 RECLAIMING BACKLANES

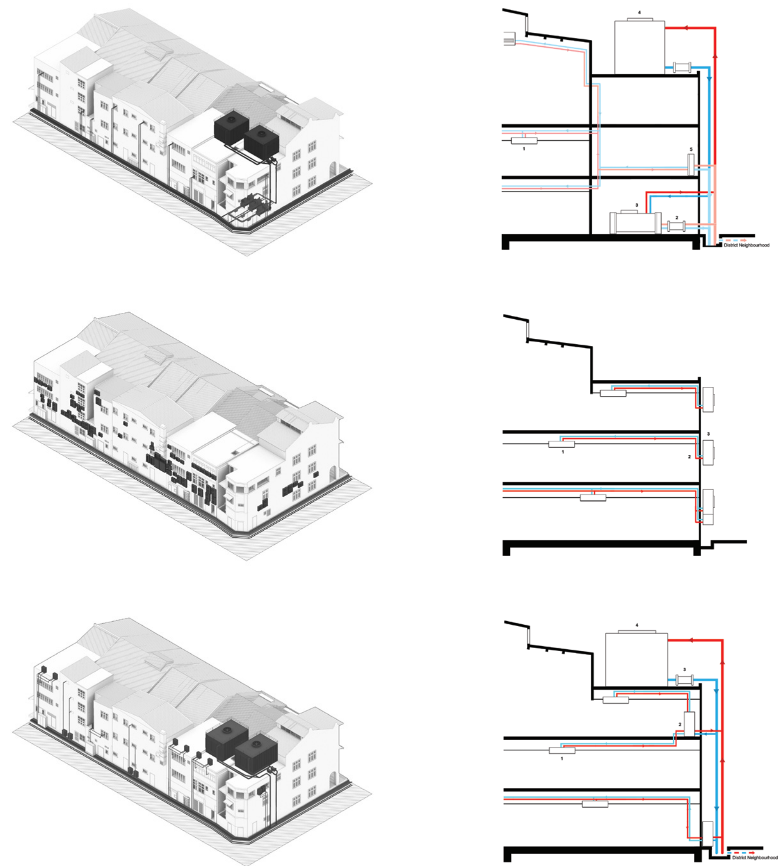
marcel brülisauer

Shophouses clusters, built from rows of historic buildings with mercantile-type occupancy common in South East Asia, are increasingly the subject of urban regeneration, often situated in prime areas of the city. The shophouses are grouped around and separated by small lanes at their back, which are noisy, dirty and thermally uncomfortable because of the number of air-conditioning units, other infrastructures and service functions. By extending the dialogue between heritage conservation, urban design and building technology beyond the physical mass of shophouses, these backlanes offer a remarkable prospect to act as strategic urban attractors.

While the thermal conditions of the tropical climate require some sort of air-conditioning of these buildings, the prevalence of air-cooled split type air-conditioners results in entire façades being covered in this simplest and cheapest cooling equipment, at the lowest energy efficiency. It also creates a hotter urban microclimate, nudging the conditions of valuable urban spaces beyond acceptable outdoor thermal comfort, a visible and perceptible consequence of the energy used for air-conditioning.

A systems approach to building climatisation through neighbourhood-scale cooling systems would not only allow increasing energy efficiency by up to 50% but also freeing backlanes from excess heat, noise and bulky installations on the back façades. A key element is to reject the heat in a centralised evaporative cooling tower on a rooftop, thereby reducing the temperature lift of the chillers and improving their energy performance. While shared cooling infrastructures – either district cooling systems with central chillers or heat bus systems, a combination of decentralised water-cooled split units connected to an evaporative cooling tower, – are a novelty for low-rise neighbourhoods in the tropics, our studies have demonstrated their technical, economic and operational feasibility.

This technical refurbishment can be used as a trigger to improve the overall pedestrian connectivity, increase the spatial quality and usability of the backlanes. While all these aspects have their value and justification on their own, only their synergetic combination can unlock the full potential hidden in these neglected urban spaces and reprogram the backlanes into a viable space. Originating from speculative, interdisciplinary studies at the Future Cities Laboratory, the design team uses the backlane model and the book to showcase visions for different backlanes in Singapore.



Cooling systems: centralised, decentralised, heat bus (top- bottom)

TEAM: Marcel Bruelisauer, Sonja Berthold, Gideon Aschwanden, Zuliandi Azli, Iris Bell, Kees Christiaanse, Matthias Mast, Forrest Meggers, Edda Ostertag, Patricia Pontau, Christian Ribback, Arno Schlueter, Cheng-Kai Wang, Lei-Ya Wong
Future Cities Laboratory, Future Resilient Systems, ETH-Singapore Centre, ETH Zürich

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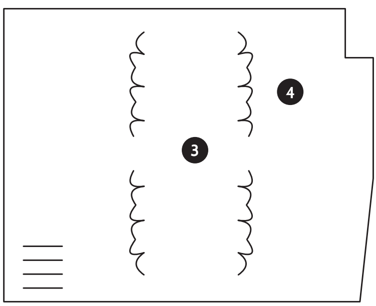
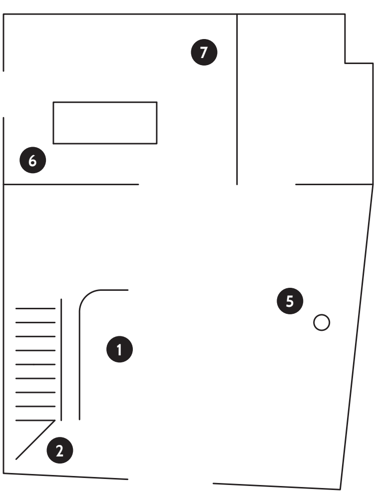


UPPER LEVEL

3 Thermally Alive Space *Dorit Aviv & Forrest Meggers*

4 Creating Climate *Kipp Bradford*



LOWER LEVEL

1 Body Building *Andrew Cruse*

2 Thermal Effusivity *Kiel Moe*

5 A New Type of Ventilation *Sal Craig & Forrest Meggers*

6 Reclaiming Backlanes *Marcel Brülisauer*

7 Reference Library