WARMTH

by

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Warmth

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Abstract

Warmth correlates with an inclusive feeling of comfort, both thermally and psychologically. Current practice is preoccupied with preventing heat loss and maintaining a constant temperature and relative level of humidity throughout spaces and does not consider occupancy. This mechanical approach considers warmth from an engineering perspective and does not take into account the human senses. An architectural approach to designing for warmth should on the other hand consider these senses. Ideally, it would create milieus that allow inhabitants to engage comprehensively with their space even as they experience awareness and appreciation of the thermal processes at work there. It is the goal of this thesis to develop viable architectural strategies to provide warmth.

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01 Introduction

"The promethean technology that was arguably the origin of civilization – the fireplace – has now more or less disappeared as a discrete object or place... Whereas the first cultures were supposedly formed by gathering around fires (according to Gottfried Semper), and whereas fireplaces were the focal point of dwelling (literally the "focus," in the Latin etymology) until the early 20th century, today, this centre cannot hold. The former tasks of the hearth – heating, cooking, lighting, a gathering place and focal point for media and culture – have been divided up among multiple devices, and/or dispersed like tentacles through systems that penetrate every hidden space of the building.¹"

This excerpt from *Elements of Architecture*: Fireplace points out that the fireplace not only provides heat and light but also creates a gathering place and a centre of culture and communication. The various functions that a fireplace fulfills mean that the warmth it provides is holistic: its ambiance and sound frame a tranquil atmosphere for intimate gatherings and conversations, and its radiant heat constructs a comfortable thermal environment. As noted in the passage above, the tasks of the fireplace have been divided up between several systems and appliances that effectively fulfill its pragmatic roles of lighting, cooking, and heating. On the other hand, the radio, television, computers, and smartphones have unfortunately replaced its social roles. The result is that ambiance and warmth are missing from many of our buildings today.

Warmth delineates both a thermal environment and a social milieu. Heat energy constantly moves from warmer to cooler areas as it seeks equilibrium, and hence the thermodynamic aspect of warmth fluctuates as long as temperature variations persist. Memory and experience also affect our perception of warmth, with textiles providing one example. Soft blankets and clean bed linens may evoke pleasant memories and thus elevate our perception of warmth.

Social interactions can be affected by perceptions of warmth². For instance, touching objects of different temperatures when meeting someone impacts impressions of this individual's warm and cold personality traits³. Social acceptance is therefore related to warmth. Temperatures are an important consideration in design, and designing for warmth can encourage social interactions and promote a sense of community. In his 1930 article "Our Dwelling as a Problem", Alvar Aalto promotes socially responsible designs, as he writes:

"There is no sense in studying the question of how miserable are the conditions in which an individual can remain alive... What we have to consider today is the question of what requirements have to be set for the dwelling, its production, and its use when it has to fulfill all the requirements of good social conditions on a minimum income."⁴ – Alvar Aalto

Inhabitants and their perception of space are at the centre of designing for warmth. This study addresses the social, thermodynamic, biological, and perceptual underpinnings of warmth. Its goal is to foster architecture that will aid the growth of communities at the same time as it enhances inhabitants' sense of belonging not only within their buildings but also within their cities.

1.1 Warmth

"There is something basically internal about warmth, probably because we associate it with the warmth generated within our own bodies. Warmth is what's alive at the very core of things. A fire and the sun also generate heat inside of themselves. We feel their heat not so much warming our skin as penetrating into the very centre of our being."⁵ - Lisa Heschong

Warmth can be defined through several perceptive avenues. First, warmth is the feeling of pleasant and comfortable heat, as exemplified by the heat of a fireplace or the sun against the skin. Second, warmth is related to personal traits of trustworthiness, kindness, affection, and fondness. Third, warmth is associated with social or intimate states of coziness, excitement, passion, and arousal. However, warmth also connotes a heated or angry emotional state⁶. Such linguistic readings of the term "warm" were in use as early as the 15th century. The expression "warm-hearted" has been in use in the 16th century⁷.

In architecture, the term 'warm' is often used to specify the tactile and visual characteristics of building elements and to describe the atmosphere of space. Spaces can be designed to provide a sensation of warmth⁸, and thus enhance physical and psychological contentment.

1.2 Current Framework

In current practice, warmth is considered only with the connotation of 'heat'. The Ontario Building Code (OBC) frames the requirement for climate control in buildings from an engineering perspective through a consideration of the building envelope and mechanical systems. With regards to the building envelope, section 9.25.2.1 reveals the OBC's intent to ensure the provision of comfort through the reduction of heat loss and specifies that "All walls, ceilings and floors separating heated space from unheated space, the exterior air or the exterior soil shall be provided with thermal insulation... to prevent moisture condensation on their room side during the winter and to ensure comfortable conditions for the occupants"⁹.

The OBC's concern with minimizing heat loss is further demonstrated in section 5.3.1.1 that specifies "where a building component or assembly will be subjected to an intended temperature differential, the component or assembly shall include materials to resist heat transfer or means to dissipate transferred heat"¹⁰.

As per the building systems, section 6.2.1.2 specifies: "Buildings classified as Group B, Division 2 or 3 occupancies or Group C residential occupancies that are intended for use in the winter months on a continuing basis shall be insulated and be equipped with heating facilities that are capable of maintaining an indoor

Figure 3 (left): Concealed mechanical systems as expressed in the Elements of Architecture: Ceiling exhibition at the 2014 Venice Architecture Biennale.

air temperature of 22°C". As demonstrated in this section, the OBC does not require a specific method of providing prescribed temperatures. So, forced-air systems are considered acceptable for maintaining a set temperature, even though radiant heat sources provide greater comfort¹¹ and are typically more energy efficient than forced-air systems¹².

That the OBC takes only a scientific approach to climate control is also illustrated by the fact that its index does not include the terms warmth, comfort, human comfort or thermal comfort. The OBC provides a framework for buildings that maintain a constant temperature and relative level of humidity throughout spaces year-round regardless of whether the building is occupied or not. The OBC partially considers the physiological aspects of warmth, yet neglects its psychological aspects altogether. The onus is therefore on the architect to consider both physiological and psychological aspects of warmth and to provide occupants with a comprehensive and pleasant thermal and social experience.

CURRENT APPROACH: Mechanical System heat

PROPOSED APPROACH: Architecture warmth

Allan Gardens

Society of St Vincent de Paul - Mary's Home
Women's Shelter

School House -
Homeless Men Shelter

Site

Seaton House -
Homeless Men Shelter

Street Haven at
The Crossroad -
Women's Shelter

Filmores Gentlemen's Club

Ryerson University

1.3 Context

The absence of warmth is not merely evident in buildings today, but in cities as well. A vacant lot situated in downtown Toronto, adjacent to Allan Gardens and Ryerson University, reveals the absence of warmth in this area of the city. The site is located within walking distance of four homeless shelters and the infamous Filmores Gentlemen's club. Even though it faces the enchanting views of Allan Gardens, its total environment makes the site appear somber and cold. This location will be transformed into a residence for students new to Toronto.

Students new to the city of Toronto may face social, geographical, cultural, and financial obstacles that challenge their experience of post-secondary education. In response to these difficulties, the residence provides spaces for private and communal studying, and for workshops, social events, and celebrations. In addition, the residence includes a private family suite for students with dependent children. Through designing for warmth, the residence will empower newcomer students, enhance their learning experience, and provide them with a sense of belonging.

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02 Social Warmth

Physical warmth and social warmth are closely related, as feeling socially connected enhances the physical sensation of warmth. The student residence emphasizes the significance of social interaction and community gatherings through its programs and organization. The main entrance from Gerrard Street invites residents and guests to walk up a ramp then through the interior garden and into the outdoor kitchen and courtyard, or down a ramp and into the community kitchen, dining room, and the lower cave, which functions as the main space for gathering, studying in groups, and social events. The circular form of the lower cave maximizes visibility between inhabitants, and thus encourages conversations with one another. Additionally, all social spaces including the outdoor kitchen, courtyard, living room, and lower cave are connected visually through windows and skylights; this encourages residents to engage in community gatherings.

Figure 6: Ramps transport residents through the interior garden and into social and communal spaces.

2.1 Psychological Warmth

The social agenda of the student residence is in accordance with studies on social perception and interpersonal fondness that identify a relationship between physical warmth and social warmth. Social warmth is defined as “the experience of feeling loved by and connected to other people¹”. Researchers found that first impressions of individuals or groups are considerably affected by perceptions of their warm and cold personality traits. According to research in social cognition, interpersonal warmth denotes character traits such as friendliness, helpfulness, and trustworthiness².

The relationship between corporeal warmth and interpersonal warmth is explored in two experiments conducted by Lawrence E. Williams and John A. Bargh in 2008. The first experiment asked 41 undergraduates to rate their impression of an unknown individual after holding either a hot cup of coffee or iced coffee for a short period of time. Participants were asked to rate the target individual by marking bipolar scales that listed ten personality characteristics and their opposites. Five out of ten characteristics were related to warm-cold personality traits. Participants who held the hot cup of coffee rated the target individual as being considerably warmer than participants who held the iced coffee. The temperature of the coffee did not affect the evaluation of characteristics that were

not related to the warm-cold traits³. In the second experiment, 53 participants were asked to momentarily hold a hot or cold therapeutic pad and rate its effectiveness, under the guise of product evaluation. Upon completing the task, participants were asked to choose one of two rewards, either a Snapple beverage or a \$1 gift certificate to a neighboring ice cream store. These rewards were equally framed as either a gift for a friend or a personal gift, such that half of the participants were asked to choose between a \$1 gift certificate for a friend or a Snapple drink for themselves, and the other half between a gift certificate for themselves or a Snapple drink for a friend. The temperature of the therapeutic pad significantly influenced the participants' reward selection to the extent that of those who held the cold pad, 75% chose to treat themselves to a gift, whereas of those who held the hot pad 54% opted to treat a friend to a gift⁴. These experiments reveal the impact of bodily contact with different temperatures on people's social conduct and impression of others.

In an effort to explain how warm objects and warm people can yield similar affective states, Williams and Bargh turned to embodiment theorists. Results of experimentation indicated a correlation in memory between objects and occurrences that generate a similar affective response. For instance, the sensation of warmth upon taking a warm bath may extend beyond physical warmth to social warmth; childhood memories may associate the bath with protection, security, and sustenance. Caregivers impart bodily warmth when holding an infant, separation from the caregiver results in coldness; therefore, social intimacy may be associated with warmth and social exclusion with coldness⁵. Anatomical explanations involve the brain's limbic system: it is associated

with learning and memory, and communicates with sensory areas. Stimulation of various regions of the limbic system may produce sensations of anger, pain, pleasure, and sadness. Similarly, sensory stimulus may kindle elaborate and emotionally charged memories⁶.

Linguistic expressions and couplings such as 'heartwarming', 'icy stare', 'warm welcome', 'burning love', and 'lonely and cold' further emphasize a relationship between social circumstances and physical temperature. Two experiments conducted in 2008 by Chen-Bo Zhong and Geoffrey J. Leonardelli validated such figures of speech when they found that social exclusion actually feels cold. The first experiment asked 65 university students to think back to an event in which they felt either socially accepted or rejected. They were then asked to gauge the room temperature. Participants who recalled events in which they felt socially excluded estimated lower room temperatures than participants who recalled events in which they felt socially included. The second experiment employed a virtual ball game that involved actual social exclusion. Fifty-two students participated in the experiment, and were arbitrarily assigned to experience either social inclusion or exclusion. The socially included received the ball equally throughout the exercise, whereas those who were excluded received it only twice at the beginning of the game. After the exercise, participants rated their desire for five food products of varying temperatures. Participants who felt socially excluded rated warm food products as more desirable than those who felt socially included. Zhong and Leonardelli suggest that their investigation could explain affective disorders such as "winter depression", in which the cold climate may induce a feeling of social exclusion⁷.

2.2 Neurological Responses to Warmth

The relationship between physical warmth and social warmth has been further established through neurological studies that examine the insula in the brain and reveal an overlap in neural activity when experiencing social warmth and physical warmth⁸. Additionally, enhanced activity during pleasant warm stimuli has been noted in areas of the brain including the ventrum striatum (VS), pregenual anterior cingulate cortex (pACC), and orbitofrontal cortex.

Tristen K. Inagaki and Naomi I. Eisenberger investigated the relationship between physical warmth and social connectivity. Their experimentation had two goals: to discover whether a sensation of physical warmth strengthens the feeling of social warmth, and conversely, whether feeling socially connected strengthens the sensation of physical warmth⁹. Furthermore, Inagaki and Eisenberger investigated whether neural activity in the insula and VS occurs upon sensations of social and physical warmth. The experiment examined the neural activity of twenty participants who held either a warm pack or a ball, or who read supportive versus neutral letters. Subjects rated their feelings of warmth and connection after participation. This experiment revealed that participants felt physically warmer upon reading supportive messages from close friends and family, and also that they felt more socially connected when holding the warm pack. Furthermore,

Figure 8: Location of the insula in the brain

results of the experimentation show that overlapping neural activity occurred in the left VS and left middle insula both when participants read supportive messages and when they held the warm pack¹⁰.

Another experiment conducted in 2010 used an economic trust game to examine the relationship between temperature and trust behavior. The objectives of the study were twofold: to identify whether temperature priming affected levels of trust, and to discover if there was any relationship between interpersonal trust behavior and neural activity, specifically that related to the insula. In the first study, thirty undergraduates were primed either with a cold or warm pack prior to participating in an electronic economic trust game with an unknown teammate. During the second study, neural activity was investigated via Magnetic Resonance Imaging (fMRI) conducted when participants touched cold and warm articles, and also while they formed decisions relating to trust. The first study found that participants primed with a cold pack invested less money in the game than participants primed with a warm pack. In the second study, activity within the left-anterior insula occurred while processing trust decisions subsequent to experiencing cold temperature, but not after experiencing warmth. These findings suggest that physical temperature affects interpersonal trust, and that activity within the insula upon contact with a cold object is conducive to negative expectancies and therefore greater risk aversion¹¹.

2.3 Social Core

The social spaces of the student residence are all located at its centre: the outdoor kitchen and living room overlook the courtyard and the lower cave is situated underneath. The courtyard invites residents to meet and dine around the fireplace, and provides children with a safe outdoor play area, where they can run around and climb the lower cave's roof. The outdoor kitchen is located between the garden and courtyard; it is bordered by a glass wall that can fold to open directly onto the courtyard during the summer. The living area boasts a grand fireplace and high ceiling and thus forms a space large enough for studying in groups, as well as for cultural and communal activities. The lower cave is centered underneath the courtyard, with an oculus that brings natural light into the space and provides playful interaction between the outdoor and indoor spaces. Centering the social spaces enhances visibility between the various gatherings and allows parents in the family suite to watch their children playing outside.

Figure 9 (left): Social spaces are situated at the core of the residence, whereas private spaces are located at the northern and southern ends.

Figure 10: From left to right, entry floor, second floor, and third floor
Figure 11 (right): Visual connection between social spaces

Robertson House in Toronto has elements of organization that are similar to those of the student residence. The house was completed in 1998 and designed by Hariri Pontarini Architects. The social spaces of Robertson House, including the mothers' lounge, story-room, and a large dining hall, were organized around the central courtyard, thus allowing mothers to watch their children playing outside. Bedrooms are situated on the upper floors and their modest scale encourages the inhabitants to spend time downstairs and build relationships with other residents¹².

Figure 12 (left): Robertson House by Hariri Pontarini Architects
Figure 13: Design charrette exploring the concept of varying scales

The scale of each space within the student residence is dependent upon the scale of the activity it was designed for. The living room, for example, is intended for large gatherings, and therefore incorporates a higher ceiling and generous floor area, whereas bedrooms and reading spaces are proposed for one or two people, and hence feature a lower ceiling and smaller footprint. The concept of varying scales has been experimented with through the design of a small rectilinear house with spaces of different dimensions carved into the block. A horizontal strip across the house allows cross ventilation and an appreciation of the landscape from every direction. Small apertures in the roof are designed to bring light into the space from varying angles, thus creating a perception of time. The diversity of scale prevents monotony in organization of spaces and also creates varied climates within the residence.

Notes

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03 Thermodynamic Warmth

The second law of thermodynamics states that heat naturally flows from hotter to cooler areas. Heat transfer occurs as long as temperature difference persists. Conduction, convection, and radiation are the three processes of heat transfer within buildings. Conduction is the process of heat transfer through direct contact between objects, and is the result of collisions between abutting molecules. Convection is the process of heat transfer through the motion of molecules in gas or fluid such as water or air. Radiation is the discharge of energy via electromagnetic waves from objects with higher energy intensity to objects with lower energy intensity. Electromagnetic radiation is emitted and absorbed by every object in space and does not require a mediating mechanism for transfer. Furthermore, electromagnetic radiation occurs almost instantly and hence can modify the thermal environment very rapidly¹.

Heat is a dynamic phenomenon, not a constant condition. Nevertheless, thermal uniformity prevails in most public and private buildings in North America and requires a considerable amount of energy to maintain². Lisa Heschong, author of *Thermal Delight in Architecture*, opposes the erasure of thermal variation, as she compares between the thermal environment and food:

"Food is as basic to our survival as is our thermal environment... Our level of understanding makes it theoretically possible to provide for all of our nutritional needs with a few pills and injections. However, while eating is a basic physiological necessity, no one would overlook the fact that it also plays a profound role in the cultural life of a people. A few tubes of an astronaut's nutritious goop are no substitute for a gourmet meal. They lack sensuality – taste, aroma, texture, temperature, color. They are disconnected from all the customs that have developed around eating... The thermal environment also has the potential for such sensuality, cultural roles, and symbolism that need not, indeed should not, be designed out of existence in the name of a thermally neutral world"³.

The commonplace steady-state approach minimizes microclimates that are natural to most buildings. For example, a house that is exposed to direct sun from every direction would present a warmer eastern area in the morning, a warmer western area in the afternoon, and a cooler northern area throughout the day. Such microclimates provide an opportunity for habitation that is dynamic according to the time of day and type of activity taking place. In some cultures, residents migrate within their houses according to the daily and yearly range of microclimates. For instance, courtyard houses are common in Arab settlements; not only are they effective in dealing with the desert sun, but they also offer the privacy that is desirable in the Muslim world⁴. Traditional houses in Tunisia, for example, are two-stories tall with a central courtyard and colonnades on

every side. During the summer, families spend their day at the lower level, where the thermally massive structure offers a retreat from the scorching sun; nights are spent on the open roof, where the clear sky provides a refreshing conclusion to the day. This occupational pattern changes during the winter: exposure to direct sun makes the open roof and upper colonnades desirable during the day, while heat radiating from the walls and lower level creates warmth on the upper level at night⁵.

Figure 14: Courtyard
of a house in Cairo

Figure 16: Southern roof is oriented to provide maximum natural light into the courtyard, interior garden, and lower cave

The student residence harnesses the motion of heat energy and makes use of various techniques to elevate and decrease the ambient temperature, producing a thermal landscape that supports the varied activities of the inhabitants. The greatest amount of warmth is necessary at the centre of the building, where social activities take place. To this end, the roof of the southern building and the oculus of the cave have been carefully oriented to provide maximum natural light into the courtyard, interior garden, and lower cave. Additionally, the core incorporates radiant heat sources that include three fireplaces, hydronic thermally active surface floors, and a large interior garden. The garden rises three stories in height and provides ample space for plants to bloom throughout the year. Heat energy from the sun is stored during the day in concrete floors and in the soil which has a high thermal mass, and is reradiated into the space at night. Private areas for sleeping and studying are located at both southern and northern ends of the residence. These spaces are smaller in scale to reduce heat loss. They feature hydronic, thermally active surface floors and walls, instances of enhancement of warmth perception through textiles. Cooling throughout the building is provided via both natural ventilation and the hydronic, thermally active surfaces that absorb excess heat.

Figure 15 (left):
Interior garden

Shading Devices on south facing windows

March 20/September 22

June 21

December 22

Figure 18: Winter occupation at the lower cave and interior garden versus summer occupation at the courtyard and upper levels

Seasonal transitions within the student residence are anticipated. During the winter, residents may prefer to spend time at the lower cave; its central fireplace and kitchen stove enclose a haven of warmth. The oculus not only acts as a chimney but also leads to awareness and appreciation of the experience of warmth as it provides a constant reminder of the cold weather outside. During the summer, social gatherings would likely occur primarily in the outdoor kitchen and courtyard where a refreshing atmosphere is produced by the garden and natural landscape.

3.1 Thermodynamic agents of Warmth

The Architecture of the Well-Tempered Environment by Reyner Banham is often discussed in relation to controlling the interior climate. In his famous parable, Banham describes a savage tribe reaching his evening campsite that is equipped with great quantity of fallen timber. The tribe may choose to harness the wood in two ways, either by constructing a shelter or building a fire. Both ways require energy to maintain homeostasis. Banham suggests that for mankind to advance and develop higher forms of culture, it is necessary to have technologies that provide a comfortable environment and thus enable leisure time, unlike the savage tribe that had to concentrate all its time in maintaining homeostasis⁶. To support his contention, Banham turns to the law of conservation of energy, which asserts that energy can convert from one form to another, but cannot be produced or destroyed. Any energy used for thermoregulation would not vanish, but rather would be utilized to advance society through participation in cultural, social, and political agencies⁷. Nowadays, human habitation of almost every climate is made possible due to technological advancements that separate the interior climate from exterior conditions.

3.1.1 Fire

"Fire gives a flickering and glowing light, ever moving, ever changing. It crackles and hisses and fills the room with the smells of smoke and wood and perhaps even food. It penetrates us with its warmth. Every sense is stimulated, and all of their associated modes of perception, such as memory and an awareness of time, are also brought into play, focused on the one experience of the fire"⁸.

Fire constitutes the earliest mechanism that allowed humanity to manipulate their thermal environment, and distinguishes man from other mammals and living organisms that rely on the climate and their own metabolism for warmth⁹. The discovery of fire is often associated with the origin of civilization, as stated by Vitruvius:

"It was the discovery of fire that originally gave rise to the coming together of men, to the deliberative assembly, and to social intercourse"¹⁰.

Fire was originally used mainly for functional purposes. Josep Fernandez, fireplace excavator, states that during the Paleolithic period the hearth was the impetus for the evolution of several adaptive advantages and survival strategies. Fire provided a source of heat, intimidated predators, and was useful for cooking and lighting. Cooking practices elevated the nutritional value of certain foods by eliminating parasites and toxins and by permitting preservation through smoking. The hearth in its role as a centre for events was instrumental in the advancement of language. The tasks involved in preparing and maintaining the fire required

coordination of responsibilities in the group, and hence advanced hierarchy and organization¹¹.

The dynamic nature of fire and its appearance gave it spiritual significance; to the extent that some propose that the first shelters were designed to protect fire from the elements¹². The earliest shelters of numerous cultures constituted solely of a central firepit enclosed by a compact circular structure. During the Middle Ages in Europe, open fires that released smoke through an opening in the roof gable continued to be popular. These fireplaces did not warm houses efficiently and caused severe heat loss problem. Chimneys were developed toward the end of the Middle Ages, first from combustible materials such as wood that triggered devastating fires, and later from noncombustible and thermally massive substances such as stone or brick that stored the heat of the fire and reradiated it into the space¹³.

Heat loss with chimney use was not as substantial as that occasioned by open fires. An added benefit of chimney use was that they minimized the danger of fires from sparks. The chimney encouraged the development of small rooms and permitted privacy

Figure 19: Open hearth at the centre of a medieval house

within a house; residents no longer had to stay close to a central fire to remain warm, and could retreat to separate rooms¹⁴.

During the 1600s in England, forests were consumed for the construction of ships and also to produce charcoal for metallurgy; firewood became scarce and open fires were less common. They did, however, retain popularity due to their charm and ambience, and continued to be used even though more efficient heat sources such as coal fires and closed stoves were available¹⁵.

Louis Savot, a Parisian physician, was the first to examine the impacts of fireplaces on sanitation in the 1600s. He found smoky chimneys to be particularly troublesome and attempted to address the issues they presented by designing new types of fireplaces and by the creation of smoother flues. By making fireplaces narrower, Savot reduced the amount of cold air that entered the fire from either side. Smoother flues reduced the friction created by rising

Figure 20: Chimney development:

1. Open central hearth necessitated a tall ceiling to inhibit sparks from inducing fires.

2. The original chimney occupied an entire structural bay and transferred smoke out through a louvered opening at the roof.

3. The smoke hood was structurally independent and initiated the development of separate spaces within the house.

4. Brick chimneys fostered the development of separate rooms, which maintained a comfortable temperature through the chimney's thermally massive construction.

smoke. His initiatives were helpful in dealing with problems created by smoke, although they did not eliminate them completely. His work utilized principles of convective heating, as the fireplace warmed the space through both radiation and convection¹⁶.

During the 18th century, fireplaces continued to draw the attention of significant figures; their goals were to prevent smoke from entering the house, to minimize heat loss through the chimney, and to reduce fuel consumption through designing more efficient systems. Count Rumford designed a taller, shallower fireplace with tapered edges; his design concentrated the fire and eliminated excess space that could prevent the smoke from going up the chimney. His fireplace drew smoke faster; burned hotter; and retained heat better. It became extremely popular across Britain and the United States¹⁷. Benjamin Franklin also advanced the traditional fireplace through his design of the Pennsylvania stove, also known as the Franklin stove, an iron insert designed to be placed within an existing firebox. The Franklin stove provides both radiant and convective heat. Air enters the stove through an underfloor duct and circulates via a succession of baffles at the back of the fire; it finally reenters the room through side vents. Although widely publicized, the Franklin stove sold poorly due to its complexity¹⁸. Nevertheless, it inspired the concept that fire could indirectly heat

Figure 21: Count Rumford
Fireplace

every part of a building by heating air and circulating it throughout spaces. It marked the change from radiant to convective heating¹⁹.

Since the 19th century, the original tasks of the fireplace have been allocated to various discrete technologies. The metal stove supplies cooking necessities; hidden furnaces or boilers fulfill the heating criteria; light bulbs and strips provide light; and radio, television, and computer deliver entertainment and to some extent replace storytelling. The upshot of all this is that fireplaces in the developing world have become redundant as far as utilitarian considerations go. However, they can still fulfill such practical needs as enhancing social settings, identifying a focal point for gathering, and augmenting the perception of warmth²⁰.

Although air could effectively heat or cool a space, it does not stimulate the senses as fire does, and therefore the thermal experience it offers is a limited one. Fire provides a dynamic focal point of warmth and light that constantly changes in form and intensity. The student residence includes one exterior wood fireplace and three interior ones. They are situated in social gathering spaces such as the outdoor kitchen and courtyard, living room, and lower cave. They are intended to both heat the spaces and to provide a pleasant social ambiance for social events. Active participation of the residents will be necessary to keep the fire burning; this will lead to collaboration and to spending time together.

Figure 22: Fireplaces located in social spaces

3.1.2 Air

In the early 18th century, awareness of the damaging effects of pollution on health led to attempts to manipulate heated air. Natural ventilation strategies to generate and intensify air currents were developed utilizing cross ventilation and fire. Fire would be subsequently employed to heat ventilated air, a strategy that evolved during the 18th and 19th centuries as advances in fireplace design significantly improved the convective transfer of heat. The new fireplaces would come to constitute prototypes for the central heating and ventilation systems that emerged towards the end of the 19th century²¹. A further adaptation was to incorporate cooling into the same system.

Early attempts to mechanically cool air included use of ice and fan systems, where supply air would be cooled by several degrees through incorporating ice racks into forced ventilation systems. However, the extensive infrastructure as well as the short supply and cost of ice rendered these systems rare²². The ubiquitous employment of air conditioning came about during the twentieth century, following Willis Haviland Carrier's advancements. Carrier discovered that air could both be dehumidified and cooled by

Figure 23: Air conditioning advertisement

transferring it through a spray of cold water. Cold air retains less absolute humidity than warm air; the spray of cold water would chill the air and remove the excess humidity. The temperature of the spray of water would determine the amount of humidity left in the air. The air would then be reheated to a comfortable temperature and transferred into the room. Consequently, the air produced would be at exactly the desired temperature and relative level of humidity²³. Carrier's greatest contribution was the development of the psychrometric chart, which presents quantifiable relationships between heat and humidity.

The development of air conditioning led to other technological advancements such as the construction of airtight buildings, thin curtain walls, deep floor plates and ample electrical lighting. Larger populations and the convenient availability of electrical equipment and lights led to more generation of heat and to the need for further air conditioning. In response to this need, sun penetration was minimized, windows were sealed, and interior spaces became increasingly unpleasant. During the 1970s, due to the energy crisis, engineers attempted to conserve energy by reducing prescribed air changes and recirculating the conditioned air inside. This method caused problems related to sick building syndromes²⁴. Kiel Moe (2010) argues that to reduce energy consumptions and to increase comfort levels, air should be used to ventilate space, while water, which is 832 times denser than air, should be used to thermally condition a space. This method is often utilized in buildings with thermally active surfaces.

3.1.3 Thermally Active Surfaces

Thermally active surfaces are grounded in radiant transfer of heat. Water is denser than air, and can therefore carry a greater amount of energy; hence thermally active surfaces are more energy efficient. Air systems for humidity control and ventilation are nonetheless required in buildings regulated by thermally active surfaces. However, the scale of accompanied air systems is typically much smaller than the scale of systems that use conditioned air only. Further benefits to thermally active surfaces result from the utilization of complete surface areas that minimize thermal variations and lead to less radiant asymmetries. Reducing thermal asymmetries indicates that minimal supply energy is required to maintain a comfortable ambient temperature. Additionally, large areas of thermally active surfaces can provide a comfortable environment by utilizing lower temperatures for heating and higher temperatures for cooling than are necessary in conventional HVAC systems²⁵. Cooling via thermally active surfaces is inherently different from air-based cooling. Air-based cooling focuses on chilling the air to counterbalance the temperature of surfaces within a space and to carry heat energy away from the body via air currents. Thermally active surfaces, on the other hand, cool spaces by absorbing heat energy and thereby preventing the building from getting hot. To prevent condensation, the temperature of thermally active surfaces should never be close to the dew-point temperature of the air in a building; high-temperature cooling is significant in preventing condensation. Heat energy will be absorbed by thermally active surfaces as long as they are colder than the body. Therefore, the required temperature to prevent the space from getting hot does not need to be close to the dew-point temperature²⁶. Thermally active surfaces are constructed with durable, massive materials such as concrete and constitute the building structure, envelope, mechanical systems, and various interior surfaces. Buildings that utilize thermally active surfaces are durable, energy efficient, and easily maintained; they therefore have lower life cycle costs.

There are several types of thermally active surfaces; the most typical being a hydronic system cast into the bottom part of a concrete slab²⁷.

Thermally active surfaces in architecture have been utilized in a variety of ways throughout the world, and date back as far as 1,000 BCE in Northeast Asia. Early examples include the Chinese Kang, the Korean Ondol and the Roman Hypocaust. They utilized both convective and radiant heat, as thermally massive surfaces would absorb heat energy from hot combustion fumes passing underneath them on their way out through a chimney²⁸. The Chinese Kang originated in northern China and has been used to date for cooking, dining, gathering, and sleeping. Houses may have one or more Kang, depending on the number of residents and the privacy they desire. Kang is a thermally massive platform that is roughly 70 cm high by 2-meters wide and stretches through the length of the room to roughly 3-4 meters. The Kang bed is attached to the kitchen stove on one side and to a chimney on the opposite side; smoke from the kitchen stove passes through noncombustible flues underneath the thermally massive platform and out through the chimney²⁹. Two types of Kangs exist today: grounded and elevated. A grounded Kang is attached to the floor through an adobe or brick base. Numerous poles distributed equally support

Figure 24: Chinese Kang

an upper plate. Smoke from the stove passes through the poles, keeping the upper plate warm throughout the day. An elevated Kang is raised above the floor by 20-30 cm tall columns that form an insulated layer of air underneath and reduce the heat loss through the base. Both grounded and elevated Kangs are in use today; the elevated Kang utilizes heat from smoke more efficiently and improves the uniformity of the upper plate temperature³⁰.

Similar to the Chinese Kang, the Korean Ondol, which stands for “warm stone” in Korean, encompasses a separate fireplace in the kitchen that transfers its smoke horizontally underneath a raised floor before escaping through a chimney on the other side. The raised floor constitutes the living space of the house, and was constructed of stone floor slabs covered with clay and layers of oiled paper and floor mats on top. This system gave rise to several cultural norms, including the practice of occupying the house barefoot and of sleeping on the floor. Moreover, the Ondol established the spatial hierarchy of the living space in which the eldest were closest to the fireplace, where the floor was warmest³¹.

In the west, the Roman Hypocaust was used to heat private homes, baths, and public structures by utilizing hot combustion air from a furnace that passed through floors and walls and out via chimneys embedded in the masonry envelope. The hypocaust was used to heat both air and water for baths³².

During the 18th and 19th centuries, the development of metallurgical applications and processes resulted in the widespread use of piped steam and hot water for heating throughout Europe. Heat energy was circulated via steam through radiators and convectors. In some cases, steam was circulated via pipes embedded within walls; this system is an example of thermally active surfaces and is similar to the thermally active surfaces used today³³.

Thermally active surfaces became more popular and effective during the 20th century with the increase in quantitative knowledge

of radiant heat transfer. Commercially available hydronic systems were designed as early as 1908 by Arthur H. Baker, an English professor; he developed a hydronic system that transferred heat through small metal pipes embedded in concrete and plaster within floors and ceilings. In the 1930s, thermally active floor slabs were commonly featured in Frank Lloyd Wright's Usonian houses. Wright's system incorporated cast iron or copper pipes inserted into sand and crushed rock placed either underneath or within a concrete floor slab³⁴. Strategies to quantify radiant heat transfer and its impact on human comfort were examined in Great Britain prior to and after the Second World War. Particular attention was given to the effects of radiant heating on the comfort and productivity of children in schools³⁵. Thermally active surfaces were extensively used in the United States after the Second World War. James Marston Fitch identified their benefits in his book *American Building: The Environmental Forces that Shaped It*, and suggested that six-sided thermally active surfaces are most effective in comfortably heating and cooling, as they provide radiant symmetry and thus necessitate less supply energy³⁶.

Many of the hydronic systems installed in the twentieth century failed due to their materiality and methods. The widespread use of metal tubing led to various complications; their preparation was labor-intensive and they were prone to leakage, and expensive to install and to fix. The reputation of hydronic radiant systems in the building industry was ruined. However, the development of cross-linked polyethylene tubing (PEX) in 1968 by the German engineer Thomas Engel resolved issues and provided a system that lasted longer than the concrete that typically encased it. Advances in PEX tubing are still being made; these include enhanced durability and greater thermal transfer through oxygen-proof exterior barriers. Hydronic systems nowadays are reliable, durable, and take less time to install due to PEX tubing, systemized fittings, and associated technologies. The result of all this is that thermally active surfaces are gaining momentum in Central Europe, China, and British Columbia³⁷.

Figure 25: Zollverein School of Management and Design by SANAA

The Zollverein School of Management and Design in Essen, Germany exemplifies a contemporary application of thermally active surfaces. The Zollverein School was completed in 2006 and designed by SANAA with Transsolar KlimaEngineering. The school is situated in the Zeche Zollverein colliery in the Ruhr region of western Germany. The colliery concluded its operations in 1993, and has since been recognized as a UNESCO World Cultural Heritage Site. The Zollverein School is part of a larger masterplan for the Zollverein area completed by The Office for Metropolitan Architecture (OMA). The school has an almost cubic volume: 35 meters in width, length and height, with four levels of public spaces, design studios, workspaces, enclosed offices, seminar spaces, and a partly enclosed roof garden. Three vertical cores and two structural columns are the only structural elements interrupting the otherwise open floor plans. After closing the colliery, the 1,000-meter deep mineshafts were filled with water, to enable future access to the mines as needed. Water from the shafts is pumped into the neighbouring Emscher River; at the pump's depth, the water temperature is constantly 29 degrees Celsius. The thermal strategy of the Zollverein School relies on the free energy provided by this water³⁸. It features a unique thermally active surface building envelope, whose reduced thickness allows for the attainment of architects' aspiration of admission of a

Figure 26: Hydronic thermally active surface pipe layout

Figure 27: Zollverein School of Management and Design by SANAA

specific amount of daylight. The building envelope provides active thermal insulation; a water-to-water heat exchanger situated in pump stations atop three shafts draws heat energy from the water. This heated water circulates through the thermally active surfaces of the school, including its entire envelope. The thermal barrier, air barrier, water barrier, and vapor barrier are all encompassed in the 305-mm-thick concrete envelope. The pipes within the walls are spaced 405 mm apart, generating surface temperatures between 18 to 22 degrees Celsius. Additional thermally active surfaces include the 455-mm concrete floor slabs with hydronic tubing that are situated at the bottom part of the slab. To minimize the weight of the floor, 400-mm-diameter rubber displacement volumes were cast into the slab; structural concrete is positioned at the floor surfaces, where it is most needed. Raised access floors on every slab accommodate the necessary space for air supply, wire administration, and a means of approach to hydronic system manifolds³⁹.

The Zollverein School integrates the free energy available on site to regulate the temperature of the facility via thermally active surfaces in the form of a single layer concrete envelope and concrete floor slabs. Consequently, the School consumes 75 percent less energy, emits up to 31 tons less carbon per year, and is cheaper to heat, saving approximately 7,000 euros annually⁴⁰.

The Fred Kaiser Building at the University of British Columbia is a Canadian precedent of contemporary thermally active surfaces. This five-story, 8,918-square-meter facility for the Electrical and Computer Engineering faculty was completed in 2005 and designed by architectsAlliance in collaboration with Omicron Engineers. The facility encompasses classrooms, offices and laboratories. Heating and cooling are delivered through thermally active concrete floor slabs. A cooling tower produces cold water for the absorption, or cooling cycle, of the thermally active surfaces⁴¹. The building is entirely enveloped with glass; incorporating low-emissivity-coated clear glass on the ground level and seventy percent ceramic frit pattern on the upper levels minimizes heat loss and manages solar heat gains. Overall, the Fred Kaiser building consumes 31 percent less energy than the model energy code. The thermally active segment of the building consumes 55 percent less energy than the model building code for buildings within Canada⁴².

Figure 28: Fred Kaiser Building
by ArchitectsAlliance

Notes

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41. Ibid., 198.
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04 Biological Warmth

"For the human body, then, the thermal environment is defined by the behaviour of the boundary level immediately adjacent to the body... the effective surfaces of the body's thermal environment – that is, what the body 'reads' as its thermal environment – are all contained within the surrounding few centimeters of its boundary layer¹" – Michelle Addington .

As noted by Michelle Addington, the thermodynamic processes that occur within just a few centimeters from the human body determine its thermal environment. To augment thermal comfort, hydronic thermally active surfaces are implemented throughout the student residence, utilizing liquid to transfer heat energy quickly and effectively. The human body operates on similar principles: it is a hydronic thermally active heating and cooling system that circulates heat energy through the blood between the core and the skin². Another comparison of the residence to the human body can be made in regards to ventilation strategies. As in the human body, thermal conditioning and ventilation systems in the residence are separate, and they utilize liquid to regulate the temperature of the space and air to ventilate it.

4.1 Thermoregulation

Humans, and other warm-blooded animals, must maintain a body core temperature close to 37°C . A slight deviation from 37°C can cause discomfort and activate body mechanisms intended to warm or cool the body such as sweating and shivering. A large deviation from this temperature can cause hyperthermia or hypothermia, and even death. Regulation of the core temperature applies to organs in the skull, chest, and abdomen. The core temperature may vary significantly from the skin temperature, which fluctuates based on its surrounding environment³. The human body regularly loses heat: heat flows from warmer to colder areas, and people typically inhabit regions with ambient temperatures lower than 37°C ⁴. The human body must continually work to maintain homeostasis.

The human body has several systems working together to maintain homeostasis, including the nervous system, cardiovascular system, the hypothalamus, and the skin. Thermoregulation is governed by the hypothalamus in the brain, which controls hunger, sleep, thirst, body temperature, and water balance⁵. The hypothalamus receives signals from temperature receptors in the core and skin and directs various automatic and voluntary actions through nerve impulses. As body temperature lowers, blood vessels of the skin constrict to conserve heat by reducing the amount of blood that reaches the skin's surface. If necessary, nerve impulses are directed towards

Figure 30: Nervous System

Figure 31: Location of the hypothalamus in the brain

Figure 32: Cardiovascular System

the skeletal muscles to activate shivering to generate heat⁶. When body temperature rises, blood vessels of the skin dilate, permitting blood to circulate near the skin surface, where heat flows out of the body into the environment. If further temperature reduction is necessary, the nervous system triggers the sweat glands to reduce body temperature through evaporation⁷.

Heat induced by muscle contraction and as a by-product of metabolism further aids in maintaining homeostasis. The primary sources of heat include the liver, heart, brain, and skeletal muscles⁸. The heart, for example, is a collection of muscle that is responsible for blood circulation within the body; its contraction generates significant amount of heat. The cardiovascular system circulates heat throughout the body and thus prevents overheating of one area⁹. Understanding the working of the cardiovascular system aids in the understanding of therapeutic properties of heat. When localized heat is applied to an area of the body, the metabolic rate and blood circulation increase in that area. An increase in the metabolic rate helps cells multiply and replace damaged tissue, and in turn greater blood circulation supplies oxygen and nutrients for the multiplication of cells, and also removes waste from the affected tissue¹⁰.

4.2 Skin

The skin is the largest organ of the human body and is composed of the outer 'epidermis' and the inner 'dermis' layers. The latter constitutes fifteen to twenty percent of the body weight¹¹. Cutaneous receptors in the dermis, also known as thermoreceptors, cause the skin to be sensitive to temperature. The epidermis contains free nerve endings, temperature receptors that respond to either cold or warmth. There are many more cold receptors than warmth receptors¹². Lisa Heschong, author of *Thermal Delight in Architecture* (1979), argues that the thermal sense can be counted as a separate sense, as our body incorporates nerve endings whose sole purpose is to notify the brain whether a part of the body is gaining or losing heat. Thermoreceptors do not inform the brain of the exact temperature of objects; rather they identify the rate of heat loss or gain by the body¹³. For instance, the body identifies metal to be colder than wood when both are at room temperature, as metal is more conductive than wood and draws heat away from the body at a faster rate.

Figure 33: Human skin diagram
Figure 34 (background): Skin

Heat loss occurs through the skin by conduction, evaporation, convection, and radiation. Twenty percent of total heat loss occurs through conduction and convection, fifty percent by radiation, and thirty percent by evaporation. Under normal circumstances, the rate of heat loss through the body is approximately 100 J/s, or

100 W; thus the body emits a similar amount of heat as a 100W light bulb¹⁴. The number of occupants in buildings has tremendous impact on the overall heating load. The social agenda of the student residence may help to reduce the overall heating load of the building, as residents would augment the ambient temperature and reduce the need for supplementary heat.

The skin constitutes a protective layer across the whole body¹⁵. It varies in thickness as necessary between 0.5mm over the eyelids and 4mm over the palms of the hands and the soles of the feet. It varies in tightness and dryness levels throughout the body, adapts to climate, can heal itself, and is impermeable to water yet absorbs moisture¹⁶. The skin partakes in maintaining homeostasis through evaporative cooling: sweat glands release moisture that vaporizes and reduces the temperature of the body surface¹⁷. The epidermis layer is composed primarily of dead cells and is only a few cells thick; the dermis layer is thicker and made of live cells. The dead and inert cells of the epidermis ensure that the skin protects internal organs from physical, chemical and bacterial risks including contamination and damaging radiation as well as mechanical or electrical impacts¹⁸. The skin also conveys the body's emotional and physical conditions: it blushes and turns pale and gets goose bumps or sweats¹⁹.

The protective, adaptive, self-healing, and communicative qualities of the human skin have inspired architects in their design of building envelopes. The human skin also inspired the envelope of the student residence that changes in thickness, materiality, and function. The north bedrooms are enveloped with a useable double skin facade that allows inhabitants of shared bedrooms to enjoy a private and cooler environment for reading and studying facing Allan Gardens. A glass wall in the outdoor kitchen can fold to reveal the life within the complex and form a direct relationship between interior spaces and the courtyard. The remaining walls are super-insulated to increase the energy efficiency of the building and reduce its cooling and heating loads.

Figure 35: The residence is enveloped with three types of walls

4.3 Balancing Warmth

A fine line exists between feeling warm and feeling hot. It is important to prevent overheating and to provide a balanced sensation of warmth. In the residence, thermally active surface heating and cooling is coupled with interior and exterior gardens and passive ventilation systems. Shared bedrooms in its northern end are enveloped with a useable double skin façade that provides a cool area for relaxation and studying. The operable skylights within the glazed roof of the garden reduce overheating and increase air movement through the building.

Although thermoregulation is extremely important, the body can withstand, and even enjoy, a range of external temperatures, depending on the type of activity and the season. The enjoyment of thermal conditions is enhanced when contrasted with other conditions. Consider the joy of a fireplace on a stormy day, of a pool or a shaded garden during a heat wave, or of a hot tub in winter. Furthermore, experiencing one thermal extreme is pleasurable when the opposite thermal extreme is anticipated²⁰. The hot temperature of a sauna is made pleasant by the awareness that stepping outside during the winter, or soaking in a nearby pool or lake during the summer will attain thermal balance. The student residence achieves thermal balance by adjoining thermally opposite elements and materials, such as fire and shade in the interior garden, and metal and brick in the building envelope.

Figure 36 (left): Thermally active surface heating and cooling coupled with interior and exterior gardens and passive ventilation systems maintain thermal balance and prevent overheating.

The concepts of thermally active surfaces and balancing thermal warmth have been experimented with through the design of a small house. The house is enveloped by a thermally active surface in the form of a concrete shell embedded with PEX tubes that are used to transfer hot or cold water to regulate the temperature. The thermal sense is activated through the materiality and space planning of the house. The house incorporates the two opposite thermal elements of fire and water in the open space, thus forming an active thermal landscape that changes based on occupants' activities. The fireplace provides a secondary radiant heat source, adjacent to a large thermally massive table that can be used for dining or recreation.

A sink at the opposite side of the table can be used to cool the surface or make steam. The table offers an environment in which one can enjoy the warmth of the fire and the coolness of water simultaneously. Rotating the sink allows occupants to care for the large plants that cool the space through shade and evaporation and that form a privacy screen that separates communal and private areas.

Figure 37 (left, background): Silhouettes of design charrette
exploring thermally active surfaces and thermal balance

Figure 38 (left): Study model

Figure 39: Thermal landscape

Notes

1. Sean Lally and Jessica Young, *Softspace: From a representation of form to a simulation of space* (London: Routledge, 2007), 41.
2. Kiel Moe, *Thermally Active Surfaces in Architecture* (New York: Princeton Architectural Press, 2010), 70.
3. Richard P. McCall, *Physics of the Human Body* (Baltimore, Md.: Johns Hopkins University Press, 2010), 97.
4. Howard D Goldick, *Mechanics, Heat, and the Human Body* (Upper Saddle River, NJ: Prentice Hall, 2001), 128.
5. Sylvia S. Mader, *Understanding human anatomy and physiology* (5th ed.) (Boston: McGraw-Hill Higher Education, 2005), 151.
6. Mader, *Understanding human anatomy and physiology*, 78.
7. *Ibid.*, 11.
8. McCall, *Physics of the Human Body*, 97.
9. Goldick, *Mechanics, Heat, and the Human Body*, 128-129.
10. *Ibid.*, 129.
11. Ellen Lupton, *Skin: Surface, Substance Design* (New York: Princeton Architectural Press, 2002), 44.
12. Mader, *Understanding human anatomy and physiology*, 164-165.
13. Lisa Heschong, *Thermal delight in architecture* (Cambridge, Mass.: MIT Press, 1979), 19.
14. McCall, *Physics of the Human Body*, 98.
15. Mader, *Understanding human anatomy and physiology*, 78.
16. Michael Wigginton and Jude Harris, *Intelligent Skins*, (Oxford: Butterworth-Heinemann, 2002), 27-28.
17. Wigginton and Harris, *Intelligent Skins*, 29.
18. Lupton, *Skin*, 29, 31.
19. *Ibid.*, 44.
20. Heschong, *Thermal delight in architecture*, 21.

05 Perceptual Warmth

Thermal perception of a space is determined by various thermal clues. For instance, the sight of a fireplace notifies people that the room they are about to enter is warm. Aromas of food and cooking are associated with the kitchen stove, and hence provide a sense of warmth. Textiles and blankets bring to mind the warmth of the bed. Plants are associated with shade and breeze and offer a refreshing ambience. Gernot Bohme discusses the thermal perception of space in his essay *Atmosphere as Mindful Physical Presence in Space*. He writes:

"Synesthetic properties are usually seen as qualities of the senses that belong to more than one sensory field at once... a space can be experienced as cool because in one case it is completely covered in tiles, in another painted blue, and in a third has a relatively low temperature. Precisely this division of synesthetic properties in terms of the generators is interesting for architects. For what then counts when designing a space is not what properties he seeks to give the objective space, but what sensitivities he wishes to create for the space as the sphere of mindful physical presence¹".

The student residence is designed to create a sense of warmth through its materiality, as well as through its organic forms and curved details. The perception of warmth commences at both entranceways. Analysis of existing entranceways led to the development of strategies to maximize this perception. Firstly, distinctive floor treatments and overhangs have been incorporated to define entranceways and to provide shelter from the elements. Secondly, warm lighting has been added to identify the entranceway and also to let you know whether or not the residence is occupied. Thirdly, glazing has been incorporated into the main door to provide a view of the warmth within. Fourthly, plants that grow in a front garden and window planters at the back give evidence that the building is well maintained. Finally, the perception of warmth is enhanced through the materiality of the façade, which includes a combination of brick and perforated metal panels. The mass and hue of the brick create a sense of welcoming warmth, and perforated metal panels that extend from the roof envelop the bedrooms to provide a sensation of being protected.

Figure 40 (left): Main entrance from Gerrard Street
 Figure 41: Metal roof envelops bedrooms to form a sense of protection

The envelope of the building includes three primary materials: brick, metal and wood. The exterior walls are constructed of brick on top of concrete masonry units (CMU), and the roof and courtyard walls of light steel frame construction with wood and metal cladding. The building's main structural components-- its floors, interior walls and fireplaces-- are constructed of concrete. The mass and volume of brick, CMU and concrete enhance the perception of warmth of the entranceways, lower level, and interior fireplaces. The light steel frame construction and thin wood and metal surfaces provide a refreshing atmosphere within the courtyard and interior garden. The selection of materials addresses a statement made by Alvar Aalto in response to the cold climate of Finland, his native land:

"The Finnish home should have two faces. One is the aesthetically direct contact with the world outside; the other, its winter face, turns inward and is seen in the interior design, which emphasizes the warmth of our inner rooms... I see the garden and the interior decoration as a closely-knit organism."²

In the residence, the face of winter is revealed in both entranceways and in the design of the lower level and fireplaces. The face of summer is apparent in the courtyard and interior garden, as well as in the metal extension of the bedrooms. The plants, wooden guardrail, and wood cladding provide an oasis-like sense of refreshment. The guardrail, for instance, is designed to evoke an interior forest.

That materials can affect the temperature of buildings, both physically and psychologically, is discussed in *Atmospheres* by Peter Zumthor. He writes:

"I believe every building has a certain temperature... We used a great deal of wood, lots of wooden beams, when we built the Swiss Pavilion for the Hanover World Fair. And when it was hot outside the pavilion was as cool as a forest, and when it was cool the pavilion was warmer than it was outside, although it was open to the air... So temperature in this sense is physical, but presumably psychological too. It's in what I see, what I feel, what I touch, even with my feet."³

Warm material palette.....

Lighting.....

Shelter.....

Plants.....

Glazed entrance.....

Defined entrance.....

This thesis presents investigations of three well-known buildings to demonstrate the effects of context and materiality on thermal perception.

The first investigation presents the landscape and façade of Villa Savoye by Le Corbusier. This villa is situated in a suburb near Paris; it feels cool and refreshing and is perhaps most inviting during warm summer days. Wood paneling and grey stucco give it a cabin feel and a warm impression. Changing the context to a winter landscape enhances the impression of a cabin.

The second investigation studies Alvar Aalto's Muuratsalo Experimental House situated on the island of Muuratsalo. The house offers a warm and dry retreat from the damp, lush rain forest that surrounds it. Its brick façade complements its context. Photoshopping experimentation with various patterns of concrete and various finishes—polished, honed, unfinished, etc.- was undertaken. Results showed that use of concrete had the effect of giving the house a cold and somewhat industrial aspect. However, these cold tones seem refreshing when the setting is changed from lush forest to dry desert and they present a contrast to the uncomfortably hot effect that a brick façade gives.

The third investigation examines the Salk Institute by Louis Kahn, located in La Jolla, California. Its light concrete cladding harmonizes with the unobstructed view of the coast. Substituting wood panels for the concrete cladding appears incongruous with the coastal landscape. However, the wood cladding suits the building after the coastal context is changed to a lush forest.

Figure 46: Muuratsalo Experimental House by Alvar Aalto

5.1 Experiencing Warmth

The selection of materials and finishes throughout the student residence arose from studies that examined the effects of technical parameters of materials on the perception of warmth and of colour on feelings and mental state. A study by Wastiels, Schifferstein, Heylighen, and Wouters examined the perception of warmth of various interior wall substances and how this perception changed upon altering the materials' technical parameters. The objective of this study was to examine the degree to which the perception of a material's warmth can be traced to its scientific parameters. Interior walls are experienced primarily through the visual sense; however, the tactile sense does influence the perception of warmth as people periodically come into contact with wall surfaces. It also allows them to gauge through past experiences and memory how a material feels⁴.

5.1.1 Tactile Warmth

Tactile warmth refers to a material feeling cold or warm according to the sense of touch. Tactile warmth is affected by ambient temperature, thermal effusivity, and geometry of materials. Ambient temperature considers the initial temperature of a material that affects its tactile warmth; brick, for example, feels colder when exposed to freezing temperature than room temperature. Ambient temperature may vary intensely outdoors, yet typically fluctuates between 17-25°C indoors⁵. Thermal effusivity (e) accounts for a substance's conductivity (k), density (ρ), and heat capacity (c) and influences tactile warmth such that at room temperature substances with lower thermal effusivity feel warmer than those with higher thermal effusivity [$e=(k\rho c)^{1/2}$]. A substance's conductivity influences its tactile warmth to the extent that the faster a material conducts heat away from the finger the colder it feels. For example, metal feels colder than wood when both are at room temperature. At room temperature, materials with lower thermal resistance, such as glass and metal, are considered cold, whereas materials with higher thermal resistance such as wood and plastic are considered warm.

Material density and heat capacity further affect tactile warmth. Heat capacity affects a material's potential to absorb heat from its environment. The temperature of substances with low heat capacity, such as metals, quickly rises in comparison to materials with high heat capacity, such as woods. The geometry of materials also affects tactile warmth. For example, heat will be conducted away from the skin more easily by a thick rod than a thin foil⁶.

Figure 47 (left): Wood in the residence appears in plants, wooden guardrail, and wood cladding that provide an oasis-like sense of refreshment.

5.1.2 Visual Warmth

Colours and surface gloss affect the visual perception of warmth. Psychological studies state that warm colours range from yellow to red-violet, and cold colours from blue-violet to yellow-green on the colour circle. Research has demonstrated that a space that was painted orange-red was perceived to be 3-4°C warmer than a space that was painted blue-green⁷. Another study found that darker and more saturated colours increased the perception of warmth. The perceived warmth of colours is dynamic, and changes according to the context; for example, yellow-green seems colder when placed next to red and warmer when placed next to blue⁸.

The perception of warmth may also be affected by surface gloss. Glossy surfaces such as a glossy paint or glazed tiles are perceived as hard and are considered colder, while finely grained surfaces feel soft and warmer. Additionally, spaces with smooth surfaces may be perceived as colder than similar spaces with finely textured surfaces, as fine textures correspond with porosity and therefore with warmth and protection⁹.

5.1.3 Inclusive Experience of Warmth

A comprehensive perception of warmth depends on a multisensory experience. Research in non-architectural fields has established that the superiority of a particular sense in experiencing warmth is product dependent. Personal associations or memory may also impact a material's perceived warmth¹⁰.

Wastiels, Schifferstein, Heylighen, and Wouters's study of the experience of material warmth in the context of architecture examined to which degree technical material parameters are connected to the perception of warmth for a collection of building materials. Their study of 116 volunteers evaluated both independently and simultaneously the influence of tactile and visual senses on the perception of warmth. The study found that wood was perceived to be the warmest substance, followed by brickwork, blue stone, plasterwork, concrete, and finally steel, which was perceived to be the coldest substance. Furthermore, their study found that the tactile experience of warmth increases when the substance's gloss decreases. Also, the use of reddish and yellowish colours and increased saturation intensified the perception of warmth. The study found that colour had the greatest effect on the perception of material warmth. With regards to surface texture, rough surfaces were experienced as warmer than smooth surfaces¹¹.

Although colours can strongly affect the perception of warmth, studies indicate that they have a psychological impact on inhabitants. For example, experimental research in retail design found that customers preferred store environments with cool hues to those with warm hues¹². In addition, a study on the effect of colour on mood, satisfaction, motivation, and performance found that blue was most soothing and red most energizing¹³. Also, blue causes objects to appear more remote while red causes them to appear closer. Another study found that students felt happier in red rooms in comparison to yellow and neutral rooms. Students were also happier and more relaxed in blue rooms. A different study indicated that participants who worked in red spaces felt less confused or bewildered than those who worked in white or green spaces¹⁴. Yildirim, Akalin-Baskaya, and Hidayetoglu examined the effect of colour on customers' satisfaction of a café/restaurant and found that participants felt more satisfied when the walls were painted violet rather than yellow¹⁵. Their study supports the findings of Valdez and Mehrabian that cool colours are considered more pleasant than warm colours¹⁶. Experiments suggest that utilizing warm colours to enhance a perception of warmth may lead to undesirable psychological impacts on occupants. The conclusion is that other material parameters, such as thermal effusivity, surface texture, gloss, and roughness, should be utilized in designing for warmth. The student residence's use of warm colors is incidental; they are found only when they are inherent to the selected material, for instance in the use of red brick and yellowish wood in façades.

5.2 Formal Warmth

"Architecture must be modeled after the biological forms of nature"¹⁷ – Alvar Aalto

The student residence incorporates ergonomic and curvilinear forms in the design of the lower cave, the north façade reading spaces, and the interior garden floor and guardrail. The curvilinear forms accentuate areas within the predominantly rectilinear building. The lower cave and reading spaces are made more comfortable through their ergonomic designs, which encourage residents to spend time in these areas. Within the interior garden, the curvilinear floor and wooden guardrail complement the natural scenery. It is suggested that a perception of warmth and coziness is achieved through these softer and more sinuous lines. Organic and curvilinear forms have been utilized by noted architects including Alvar Aalto, Le Corbusier, Carlo Scarpa, and more recently by the Toronto-based firm Partisans.

Figure 49 (left): The building's main structural components-- its floors, interior walls and fireplaces-- are constructed of concrete

Figure 50 (left): Curved elements in the
lower cave (top) and living room (bottom)
Figure 51: North façade reading spaces

The architecture of Alvar Aalto is centered on building occupants and on maintaining harmony between man and nature. In his seminal 1926 text “From Doorstep to Living Room”, Aalto discussed the connection between interior and exterior spaces, and stated that the main entranceway should lead people directly from the exterior street to the interior garden or courtyard. The garden, Aalto exclaimed, is just as significant as any other space within a house, and offers a pleasant environment to both spend time in and gaze at¹⁸.

The relationship between the exterior and interior gardens is evident in Villa Mairea in Noormarkku, Finland, designed by Aino and Alvar Aalto in 1938-1939 for Harry and Maire Gullichsen. Occupants pass from one garden to another, beginning with an exterior canopy supported by tree trunks, through an interior ‘forest’ of wood poles bordering the staircase, and up the stairs towards an expansive view of the courtyard and pine forest¹⁹. Natural forms are evident throughout the interior detailing of Villa Mairea. For instance, the art studio is distinguished by its tall, rounded corners and by the dark- stained wooden battens that clad its exterior. The art studio was a significant part of the project, as Maire Gullichsen was an art patron; she studied art, established the Free Art School in Helsinki in 1935, and became an art collector²⁰. Further interior sinuous elements include the handrails and the fireplace. Every single-family house designed by Aalto includes no less than one open fireplace, which plays a significant part in the organization of the house, and often consists of sculptural, sinuous forms²¹. Natural forms are also incorporated outside, through the organic shape of the pool, and the undulating pathways that lead to the house.

88 Figure 53: Organic fireplace designs by Alvar Aalto

Figure 54: Villa Mairea first floor plan
[top] and second floor plan [bottom]

Villa Shodhan - Ground Floor Plan

Maison Curutchet - Third Floor Plan

Villa Savoye - Roof Garden Plan

Curvilinear forms are also a prominent feature in the dwellings designed by Le Corbusier, and particularly in his bath designs. Le Corbusier celebrated the act of bathing due to its health merits, and honoured both water bathing and sun bathing. The triumph of running water was earnestly considered in Le Corbusier's designs; he developed unique bathrooms and never restricted his designs to standard fixtures. Le Corbusier regarded bathrooms as organs of the house that necessitated a unique tectonic and formal expression. Accordingly, he utilized curved walls in many of his bathroom designs; these are reminiscent of the body they accommodate²². Le Corbusier's dwelling designs, including Villa Savoye, often feature a solarium on their roof garden. He consistently situated water to present a contrast with fire or with the sun; his roof gardens celebrated contrasting natural phenomena including rain, sun, moon and vegetation²³.

Figure 55: Diagram of Le Corbusier's curvilinear water and sun bath areas

Figure 56 (top left): Bellotto House by Carlo Scarpa
 Figure 57 (bottom left): Veritti House by Carlo Scarpa
 Figure 58: Ottolenghi House by Carlo Scarpa

Carlo Scarpa utilized organic forms in his domestic designs to create an informal, casual presence²⁴. These forms appeared in the volumes of entire buildings, and through their internal structural and organizational elements. Bellotto House in Venice, designed by Scarpa in 1944-46 exemplifies the latter, as all the spaces in the house are organized around a central spiral staircase that resembles a shell. The staircase is the focal point and most prominent feature in the house²⁵. Scarpa's use of curvilinear volumes is exemplified through the Veritti House, constructed between 1955-61 in Udine. A cylindrical form was selected in response to the narrow site, as this form prevents the formation of residual areas between the house and its perimeter walls, and also affords a smoother entranceway to the garden. A southern artificial pond completes the circular form of Veritti House²⁶. Other curvilinear elements, including round structural columns and a round bathroom plan, are presented in Scarpa's design of the Ottolenghi House that was constructed in Bardolino, Verona, between 1974-78. Ottolenghi House consists of nine columns each 88 centimeters in diameter; they delineate the boundary of the living area and mark the entrance to the garden²⁷.

Grotto Sauna in Georgian Bay, Ontario, designed by the Toronto-based firm Partisans provides a contemporary precedent that utilizes curvilinear lines to enhance the perception of warmth. The design implements several contrasting elements, including the form and materiality of the building. The rectilinear, charred-wood exterior is harmonious with the site through its position and tone; the organic forms of its apertures hint at what is to be found inside. Once inside, occupants immerse themselves in a light, undulating wooden sanctuary. The interior overlooks the lake, a view which provides a constant reminder of the cooler temperature outside and thus adds to appreciation of the pleasant warmth inside.

These precedents reveal the advantages of organic forms, which sustain harmony between man and nature; distinguish significant areas within predominantly rectilinear buildings; and create a casual atmosphere that enhances the perception of warmth.

Notes

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06 Comprehensive Warmth

As research has shown, warmth correlates with social milieus; with thermodynamic processes; with biological processes of thermoregulation; with thermoreceptors in the skin; with personal experiences and memory; and with materiality, colour, texture, and forms in space. Warmth in architecture can promote fellowship and increase trust behaviour and thereby foster community growth. The student residence boasts a holistic sense of warmth through its organization, heating and cooling strategies, materiality, and formal expression. The residence encourages social gatherings within its courtyard, outdoor kitchen, lower cave, and living room, yet it also incorporates private and quiet study areas that overlook Allan Gardens and a back lane.

Heating and cooling strategies involve the human senses, and thus enhance inhabitants' awareness of the thermodynamic processes taking place. Thermally active floors trigger the tactile sense as inhabitants feel the temperature of the slab through their feet; wood burning fireplaces kindle the olfactory, auditory, tactile, and visual senses; and the sun stimulates the tactile sense, as rays of sunlight softly touch the skin in the courtyard and on the upper levels.

As the student residence demonstrates, warmth has the potential to transcend mechanical approaches and become an architectural element that influences every design decision from schematic space planning to building materiality and detailing.

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Appendix A

Study models

Figure 64: Sectional model

Appendix B

Experiencing thermal environments

The following experiments were conducted in an attempt to explore the body's response to various thermal environments that included a bonfire, a dry and wet sauna, and pools of different temperatures. Each of these environments has a strong thermal quality that dominates its space and its experience. Each location was experienced twice. The first experience was qualitative: it examined my personal feelings within the space and my perceptions of it. The second experience was quantified: my heart rate and core temperature were measured in varied settings, as was the surface temperature of my skin and of surrounding objects, and the space's temperature and relative humidity. The experiments were not intended to represent everyone's response to thermal environments, but rather to indicate the type of experience one might have in such spaces, and the potential effects that thermal conditions have on our body.

Figure 68: Experiencing fire

Fire

Date: August 08, 2014; Location: Port Elgin, Ontario

It was pure joy to warm my legs in front of the fire, while the rest of my body felt chilly due to the cold wind. My body had to constantly work to keep warm, while my legs moved closer to and further away from the fire, as they momentarily enjoyed the sweltering heat before I had to move them back to prevent a lasting burn. To stay warm, I had to sit relatively close to the fire, as the wind chill dominated even from two meters away. The fire kept my legs warm, but I needed a sweater to keep my upper body comfortable. After several minutes, the dry heat caused my legs to feel itchy and I began to feel restless.

Quantified visit:

Date: October 20, 2014; Location: Rotem's Guest House, Moshav Faran, Israel

As I sat next to the fire my heart rate ranged from 88-90 beats per minute (bpm).

Measurements:

Core Temperature – 36.5°C

Fire area temperature – 25.7°C

Hand temperature – 37.8°C

Fire logs temperature – 176.7°C – 410°C

Feet temperature – 35°C

Surrounding stones temperature – 37.8°C – 93.3°C

Outdoor temperature – 22.4°C

Relative Humidity – 45%

Figure 69: Equipment utilized in quantified experiment

Body Blitz Spa

Qualified visit: September 03, 2014;

Quantified visit: October 06, 2014

Location: Toronto, ON.

Body Blitz is a women’s-only spa that offers three pools of varied temperatures, steam room, and infrared sauna. In my first visit I followed the therapeutic waters circuit, as recommended by Body Blitz; it directs you through warm and cold thermal zones to maintain a balanced body temperature and heart rate. My second visit required authorization to use the various thermometers and a heart rate monitor, since the spa is an electronics-free zone. After a little negotiation, approval to use the equipment was obtained under the condition that I do so discreetly and towards the end of the day. My heart rate was at times higher than expected due perhaps to nervousness or excitement. Nevertheless, the experimental results were mostly consistent with my research and expectations.

Pools area Measurements:

Core temperature – 37.5°C	Floor temperature – 29°C
Hand temperature – 35°C	Brick wall temperature – 25.5°C
Feet temperature – 33°C	Room temperature – 32.3°C
Sofa temperature – 30.8°C	Room Relative Humidity – 52.1%

Figure 70: Body Blitz Spa [west location]

Dead Sea Salt Pool

Water Temperature – 36°C

Duration – 10 minutes

Qualified visit notes:

Upon entering the Dead Sea Salt Pool, and immersing myself fully in the waters, I felt pressure against my chest and a slight stomach ache. The pain was relieved once I stood, half-immersed in water. I felt relaxed and fascinated with the central waterfall and its soothing sound.

Quantified visit notes:

As I entered the Dead Sea Salt Pool my heart rate was steady at 88 bpm but slowly rose to 91 bpm while I was fully immersed in the water. I was expecting my heart rate to remain constant in the comfortable water temperature; however, upon standing it quickly decreased to 80 bpm. At this point I got into the waters again and my heart rate remained low for a few minutes. When I got up the second time, it increased to 100 bpm, then slowly decreased to 86-88 bpm, where it stabilized. I was not nervous while in the Dead Sea salt pool, and this experience revealed to me just how attuned my heart rate was to my thermal condition.

Figure 71: Experiencing the Dead Sea and Epsom Salt pools at Body Blitz Spa

Steam Room

Duration: 10 minutes

Qualified visit notes:

The first couple of minutes in the steam room felt very relaxing and comfortable. However, as the minutes passed by I felt incredibly lazy and breathing became difficult, as the steam burned through my nose. I attempted to stand up and slowly walk about the room. Standing up made me feel dizzy, and the room felt even warmer when I was walking. I was desperate to leave after roughly 10 minutes.

Quantified visit notes:

As I entered the steam room my heart rate was at 100bpm. Initially it dropped, however after a couple of minutes it started rising again and peaked at 136. My heart rate fluctuated between 120-136.

Measurements:	Floor temperature – 48.9°C
Core temperature – 42.6°C	Ceiling temperature – 55.8°C
Hand temperature – 44°C - 47°C	Stone bench temperature – 51.9°C
Feet temperature – 40.5°C – 42.8°C	Room temperature – 44°C
Wall tile temperature – 51°C - 55°C	Room Relative Humidity – 84.2%

Cold Plunge Pool

Water Temperature – 31°C

Duration – 1-3 minutes

Qualified visit notes:

Entering the cold plunge pool is excruciatingly painful due to the freezing temperature of the water. I usually skip this pool, but for the sake of science, I was determined to immerse myself in it up to my neck. I felt like the water stabbed my skin, and I was only able to soak for a minute before storming out. I felt very lazy afterwards, perhaps due to the intense changes in thermal conditions my body was experiencing.

Quantified visit notes:

My heart rate upon entering the cold plunge pool was 100bpm, and as I was searching for air in the first 30 seconds, it increased to 120bpm. I expected it to decrease eventually, and indeed by the time I got out of the pool, one minute later, it was at 90bpm. I later entered the pool a second time to measure my core temperature; unfortunately, however, the thermometer fell in the water and broke. While trying to fix it, I realized my heart rate dropped to 76bpm. After roughly 3 minutes I gave up on the thermometer and walked out.

Infrared Sauna

Duration: 10 minutes

Qualified visit notes:

The radiant heat in the infrared sauna feels very comfortable. After a few minutes I felt very tired and feel as if my whole body is asleep. As I got up and slowly walked around, the heat became unbearable. The sauna felt comfortable as long as I did not move at all.

Quantified visit notes:

My heart rate at the infrared sauna was initially 86bpm, and increased to 106bpm, where it stabilized.

Measurements:

Hand temperature – 41.9°C

Feet temperature – 39°C

Upper wood bench temperature – 58.3°C

Lower wood bench temperature – 48.9°C

Floor temperature – 43.6°C

Ceiling temperature – 68.3°C

Wall temperature [behind wood bench] – 71.9°C

Room temperature – 51.8°C

Room Relative Humidity – 16.8%

Hot Epsom Salt Pool

Water Temperature – 41.4°C

Duration – 8 minutes

Qualified visit notes:

The sensation inside the hot Epsom salt pool was very similar to that of the Dead Sea salt pool. The hot water pressed against my chest and I had difficulty breathing normally.

Quantified visit notes:

My heart rate at the Epsom salt pool fluctuated between 106-110bpm.

Experiment Conclusion:

The qualified and quantified experiments were very different from one another. The qualified experiment allowed me to concentrate more on how I felt, and was generally much more relaxing. The quantified visit, although less calming, revealed some very interesting results. My heart rate was attuned to my thermal surroundings; although other factors such as a feeling of excitement or breathlessness caused it to fluctuate, it generally increased in warmer areas and decreased in colder areas. In the Blitz Spa, my skin temperature was 2-4°C higher/lower than my core temperature, which surprisingly increased to 42.6°C in the steam room. I was not able to measure my core temperature in most spaces as the thermometer malfunctioned in the cold-plunge pool. Although the surface temperatures were different throughout the room, the ceiling was consistently warmer than the floor. My hands were also generally warmer than my feet. Overall, each thermal zone had a strong influence on my body and left me feeling very relaxed and lazy afterwards.