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Enhancing Home Schooling Parents Through Adaptive Dynamic Interior Walls

RAOUL JOSPIN[1], TURATSINZE JUNIOR[2]

Zhejiang University, Department of Industrial Design Engineering, College of International Industrial Design, Ningbo, China [1]

Zhejiang University, Department of Industrial Design Engineering, College of International Industrial Design, Ningbo, China [2]

Abstract: This research thesis addresses the growing need for adaptive dynamic interior walls in modern home-schooling design to accommodate the dynamic nature of contemporary lifestyles and enhance living environments. By integrating insights from interior design, architecture, psychology, and engineering, this multidisciplinary study investigates the efficacy of dynamic walls in meeting the evolving needs of inhabitants. The paper begins with a comprehensive literature review, exploring historical precedents, theoretical frameworks, and practical applications relevant to adaptive interior design. Drawing from influential scholars such as Christopher Alexander and Sarah Williams Gold Hagen, the review highlights the psychological, physiological, and sociocultural dimensions of spatial design, emphasizing the pivotal role of adaptability in promoting human well-being and satisfaction in built environments. Building on this theoretical foundation, the study delves into the design development process of dynamic walls, elucidating the intricate interplay between form, function, and technology. Through a detailed exploration of material selection, structural considerations, and responsive design principles, the research illuminates the complexities inherent in creating adaptive architectural elements. Inspirations from innovative projects like the MIT Media Lab's City Home and Ori Systems robotic furniture showcase the transformative potential of dynamic walls in optimizing spatial utilization and enhancing user experience. Furthermore, the study delves into empirical findings derived from surveys, experiments, and user feedback. The collection of robust data and analysis of both quantitative metrics and qualitative responses demonstrate the profound influence of adaptive design solutions on aspects such as spatial flexibility, usability, and overall satisfaction. Concrete evidence of measurable benefits, such as space optimization and improved user experience, is complemented by nuanced perspectives from qualitative feedback, shedding light on user interactions. The versatility and scalability of dynamic walls are underscored through the inclusion of real-world case studies across diverse settings. These case studies provide tangible proof of concept, showcasing successful implementations in commercial spaces, educational environments, This research paper offers a compelling argument for the transformative potential of dynamic walls as an effective design solution. By synthesizing theoretical insights, design principles, and empirical evidence, it contributes to the discourse on adaptive interior design and provides practical guidance for architects, designers, and stakeholders seeking to enhance spatial functionality and user experience.

Keywords: Adaptive design; Dynamic walls; Home Schooling; Spatial flexibility; User experience.

I. INTRODUCTION

The area of interior design has evolved significantly over time, reflecting shifts in cultural ideals, socioeconomic requirements, and technology breakthroughs. Traditional interior design methodologies used fixed spatial arrangements and defined boundaries to separate different functional sectors inside a room. However, modern living arrangements require more flexibility and adaptation to accommodate changing lifestyles. In answer to this demand, dynamic walls have evolved as a creative way to improve home schooling ideas. This research backdrop dives into the evolution of interior design, revealing historical precursors and significant trends, and investigates the reason for using dynamic walls to fulfill the changing needs of modern living environments. The technological boom enabled kinetic architecture to make a stunning comeback and attack traditional architecture, as a result of the dominant mix of manufacturing and technology use sustained by kinetic architecture [1]. As a result, technological breakthroughs and innovations in constructing dynamic architectural skins open up new potential for designers and architects [2]. Thus, building facades are increasingly being built as complex systems of material assemblies that are sensitive to climate and energy optimization [3]. Kinetic facades have been in regular use since the 1960s. Richard Neutra designed the Los Angeles County Hall of Records in 1962, which was one of the first examples of responsive building skin [4]. Buckminster Fuller's façade for the United States pavilion at the 1967 Montreal Expo was a pioneering example of automatic climate-adaptive envelopes. This geodesic dome's skin is made of translucent acrylic panels with an inside. Throughout history, interior design has served

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as a reflection of cultural values and preferences. Interior spaces in ancient civilizations like Egypt, Mesopotamia, and Rome were filled with symbolic meaning, serving as symbols of power, wealth, and social status. Palaces and aristocratic homes were defined by costly decorations, magnificent architectural elements, and hierarchical layouts that focused on space partitioning. Similarly, during the Renaissance period, palazzos and chateaux' interiors exuded wealth and elegance by using rich materials and attractive furnishings, as well as designs inspired by classical principles of proportion and symmetry. The Industrial Revolution ushered in significant advances in interior design, marked by mass production and technological advancements. Demographic trends, such as the development of single-person households, intergenerational living arrangements, and an aging population, have highlighted the importance of adaptive living spaces that can meet a variety of needs and preferences. In this framework, home schooling environments are considered as dynamic ecosystems that must adapt to their residents' changing demands and lifestyles. The traditional separation of space into discrete rooms for various uses is making way to more open, flexible arrangements that allow for seamless transitions between activities.

Open-plan living areas, which incorporate the kitchen, dining, and living areas, for example, facilitate seamless interaction and connectedness among family members and guests. Interior design has evolved from ancient civilizations to present times, demonstrating the discipline's ongoing modification to satisfy societal needs. Traditional fixed spatial layouts have given way to a desire for flexibility and adaptability in modern living spaces. The advent of dynamic walls as a novel architectural solution reflects the changing nature of modern lifestyles and the desire for multipurpose areas. Dynamic walls, which use sophisticated materials and responsive design principles, have the potential to revolutionize home education designs allowing interiors to be transformed based on the individual demands and activities of the inhabitants. The purpose of this study is to investigate the effectiveness and practical consequences of dynamic walls in improving home education environments, as well as to contribute to the continuing discussion about adaptive interior design.

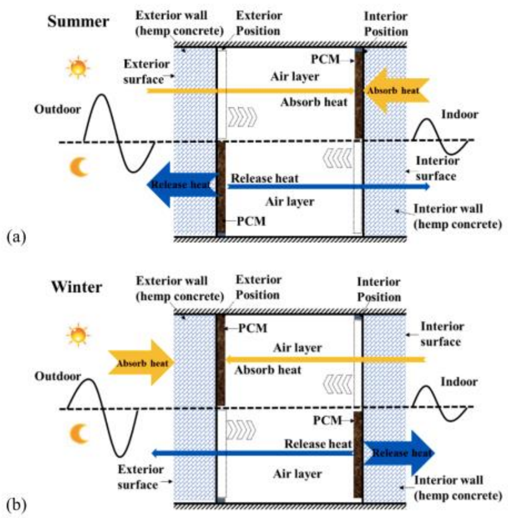

Figure. 1.3: The schematic of the dynamic wall working and heat transfer process: (a) summer conditions, (b) winter conditions.

Table 1.1 : Properties of the difference materials of the wall

Layer	Thickness (cm)	Density (kg/m^3)	Thermal Conductivity (w/(m*K))	Specific heat capacity (J/kg*K))	Phase transition temp (^{0}C)	Latent heat (kj/kg)
PCM	2	810	wcf/cm	$C_{df/pcm}$	22.26	90.4
Air layer	3	1.002	$w_{cf/pcm}$	C_{dr}	-	
HC exterior	2	487	0.125	1080	-	
Interior	10	487	0.125	1060	-	

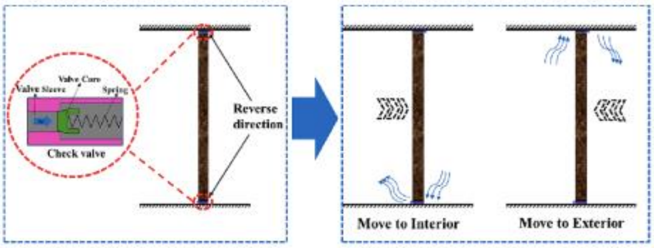

Figure 1.4: Moving details of the PCM and air layer

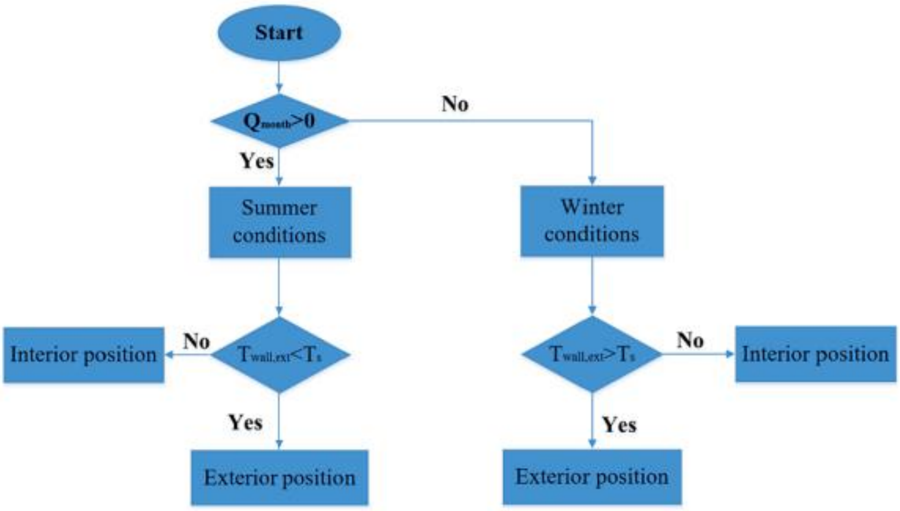

Figure 1.5: Control algorithm logic of the dynamic PCM layer.

In this investigation, considering the influence of phase transition on the thermal properties of the PCM, the effective heat capacity approach was chosen to explain heat transmission in the PCM [41]. This approach defines effective heat capacity (Ceff,pcm) and thermal conductivity (λeff,pcm) as follows:

$$C_{eff,pcm} = \begin{cases} C_1 & T < T_s \\ \frac{C_1 + C_2}{2} + \omega \times exp\left(-1.67 \times \left(T - \frac{T_s + T_f}{2}\right)^2\right) & T_s < T < T_f \# \\ C_2 & T > T_f \end{cases} \tag{2}$$

$$\lambda_{eff,pcm} = \begin{cases} \lambda_1 \\ \lambda_1 + 0.01 \times (T_f - T) \# \\ \lambda_2 \end{cases} \tag{3}$$

II. LITERATURE REVIEW

Homeschooling architecture has historically been used to shelter humans from unsatisfactory environmental circumstances. Architecture was a pioneering art form in previous centuries, distinguished by characteristics such as simplicity, organization, clear style, correct embellishment, material assembly, and so on. However, modern structures have evolved into complicated products with numerous components that must perform a variety of roles. As a result, new computational methods and techniques have been developed to aid in the design of modern complex buildings and to establish a convenient quantitative relationship between the environment and the envelope, while also taking into account the obstacles that influence building design. This has given rise to the concept of dynamic wall design in architecture, which allows for more accurate results when dealing with complicated designs. Modern architects argue that dynamic wall design is the most creative technique to grasp the development and happiness of home schooling parenting in this difficult new era of architectural trends [8]. This is an important chapter in the overall investigation of this thesis trip. As a short reminder, our primary focus is the creation of an innovative dynamic wall customized to the needs of improving home schooling and parenting building. This wall seeks to help building owners make home schooling parenting easier and more joyful by balancing the energy consumption of both static and dynamic walls in society. This chapter acts as a vital cornerstone, supporting the theoretical and empirical underpinnings that guide. We understand user-centered design, dynamic wall design, wall UI design[7], and building usability[2]. By looking into current literature, we want to gain valuable insights that will enrich our dynamic wall development process and make it more appealing to the particular dynamics of the developing home schooling environment. Our research focuses on four interconnected dimensions: user-centered design principles, dynamic UI design, development and branding, and home schooling environment case studies[9-15]. Within these domains, we want to identify best practices, difficulties, and new solutions[16] that have emerged from previous research and industry practices.

A. User Centered-Design Principles

User Centered Design is a design method that prioritizes the user's wants and overall experience with the product being produced. It is an iterative design process, which means that stages or cycles are constantly repeated to develop, improve, and perfect the product to meet the needs of the user [7]. At its core, UCD prioritizes the user in the design process, ensuring that the end product is not just practical and efficient, but also intuitive, entertaining, and personalized to the user's specific needs. The book "Fundamentals of User Centered Design: A Practical Approach" [7] elaborates on the user's involvement in the design process by highlighting "The 10 UCD commandments" such as "Thou Must Involve Users Early, Thou Must Involve Users Frequently, Thou Must Know Your Users, and Thou Must Give Users Control." This method entails actively engaging with users throughout the design process, from initial research and conceptualization to prototyping, testing, and continuous refining. By gaining a thorough grasp of users' behaviors[8], expectations, and pain areas, UCD strives to design solutions that truly resonate with the individuals who will engage with them, leading in more user-friendly and successful products. Some of the key principles governing UCD are:
In the context of UCD and product development, user focus refers to the core notion of prioritizing the end user's demands, preferences, and experiences during the design process. It entails a deep and continuing dedication to comprehending the user, their objectives, and their interactions with a product or system[10]. Designers gather information about users through interviews, questionnaires, and observations in order to gain a better understanding of their requirements and expectations. Users involved from the beginning of the design process and throughout its iterations. It is important that users are involved at each step to keep the design user centric. Their input is sought at every stage to validate and refine the design. This method is used in the development of the In Charge Health Mobile App to Improve Adherence to Hydroxyurea in Patients with Sickle Cell Disease [11]. UCT is an iterative process. Designers develop prototypes, get feedback, then redesign to improve on earlier prototypes. This cycle of a process continues until the product meets the demands and expectations of its users. UCD takes a holistic approach by considering all aspects of the user’s experience[11]. Factors such as functionality, aesthetics[12], usability, and accessibility are all included in this holistic approach. This is in order to create a balance of satisfaction across the entire design which ultimately creates a seamless and overall satisfying experience for the users. Effective communication and collaboration are required to ensure that the user's viewpoint is incorporated into the design. Collaboration is an important aspect of UCD. This requires cross-functional collaboration among designers, developers, and other stakeholders. Great ideas can also emerge from the various views in a collaborative area. Contextual inquiry requires designers to completely grasp the context in which the product will be utilized and function. This may include factors such as the user's environment, tasks, and any limitations that may affect their interaction with the product. The context of use may have a significant impact on the product's overall design. Creating product prototypes allows you to envision and test design ideas early on. These prototypes might range from low-fidelity sketches to high-fidelity interactive mockups. User comments and data from usability testing are critical for making sound design decisions. This feedback is used to refine and improve the design during each iteration cycle. UCD places a priority on creating products that are accessible to all consumers. This could include persons with disabilities, people who speak different languages, and people who have diverse levels of product experience.The emotional impact of a product is frequently overshadowed by its functionality. UCD acknowledges that the emotional parts of the user experience, such as aesthetics and the overall "feel" of the product, are just as important as the functional ones. Things such as color and materials used can heavily affect how a product makes people feel.
Designers should properly convey their design choices and logic to the entire team. This guarantees that everyone involved in the project knows and works towards the same goal.
To put the principles of user centered design into the world of dynamic wall development, developers of building real

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estate must involve renters and landlords enthusiasts into the development of their home schooling parenting [13]. This pool of people generally constitutes the majority of people who use dynamic wall applications. Usually, building owners people who are into real estate have characteristics of being competitive and motivated [14]. It's no surprise that gamification in construction has shown to be a source of satisfaction for dynamic wall users [15,16]. A study found that lovely buildings have the happiest dynamic home schooling parenting aspects, such as MIT Lab media, lying houses, swirling towers, and cities on wheels, which satisfy the needs of competence, autonomy, and relatedness for dynamic wall users [14]. Discovering these qualities in the users' home education and parenting the dynamic wall set up in their building is the result of a user-centered design process. This alone can significantly contribute to the success of these dynamic walls among architecture design enthusiasts.

B. Dynamic Wall UI Design

Usability testing is an important aspect in the design and development of dynamic walls [17], as it allows developers and engineers to evaluate how well the dynamic walls work from the user's perspective. It aids in identifying and resolving issues with user interface design look, navigation colors, and overall user experience. Usability testing guarantees that the wall is created with the user's requirements and preferences in mind. Involving consumers in the testing process allows developers and engineers to make informed design decisions based on actual user feedback, as demonstrated in the design process of Sharifa-Ha House., Tehran for architects and designers [9]. Studying the housing design's user cases[18] and iterating the building design based on them helps to improve the user's satisfaction and home schooling parenting within. For example, using the house or apartment prior to, during, or following a dynamic wall or changing appearances activity may have a favorable impact on how the user's functions and interface are created and put out. Factors such as wall alterations in the building. The residence is designed specifically for sensitive sites and offers breathtaking vistas, blending in with the surrounding scenery. A lifting mechanism raises a support column above the trees with the push of a button, allowing for breathtaking panoramic vistas. The design was based on the link between. when they will be interacting with the home schooling parenting of the houses than before applied the dynamic to the wall and the accessibility of the user to the houses in doors appearance (one handed use, voice prompt requirements, day/night mode etc)Recently a study on the exploration of the Da Vinci Tower, Dubai showed that many users of the Da Vinci Tower gravitated enjoyments towards home schooling parenting inside it because of its perceived simplicity in terms of design of wall and its various colors make it more beautiful appearances [19]. According to the study, "The study found that the amount of time spent in the home schooling parenting building when every electronic was turned off, such as a smart TV, the more positive the influence on attitude, thus affecting users' behavior." As a result, this study recommended the following recommendations: People are chasing a clearer and simpler interactive function, a simplified dynamic wall design, or adding instructions next to the new features would make the wall of home education parents more flawless and exciting. Emphasize the user's entertainment demands, create intriguing appearances to make users feel interesting, and then encourage them to continue using our dynamic wall put up in the home schooling parenting." [19].

C. Dynamic Wall Features

This feature allows dynamic walls to divide spaces into separate areas or combine them into larger open spaces as needed. Users can easily modify the configuration of the partitions to adapt to changing requirements, providing flexibility and versatility in home schooling environments. For example, a dynamic wall can transform a single room into two smaller rooms or merge multiple rooms into a spacious home schooling parenting area. Dynamic walls designed to offer the ability to change the layout and arrangement of a space dynamically. With the push of a button or through intuitive controls, users can reconfigure the positions of walls, furniture, and fixtures to create different functional zones within a room. This adaptability allows residents to optimize space utilization and cater to various activities or preferences. Dynamic walls can incorporate various embedded technologies to enhance functionality and convenience. For example, embedded touchscreens allow users to control lighting, temperature, multimedia systems, and other smart home features directly from the wall surface. Dynamic walls that equipped with smart sensors to gather data and provide intelligent automation. These sensors that can detect occupancy, lighting conditions, temperature, and other environmental factors. By integrating with smart home systems, the dynamic walls can automatically adjust settings, such as lighting levels or climate control, based on user preferences or environmental conditions. Dynamic walls can contribute to energy efficiency in home schooling spaces. For instance, it designed with insulation materials that offer improved thermal performance, reducing energy consumption for heating and cooling. Additionally, dynamic walls integrate with smart home schooling energy management systems to optimize energy usage by adjusting lighting, HVAC settings, and power distribution. Dynamic walls designed to serve as platforms for multimedia integration, enabling residents to enjoy immersive audiovisual experiences. These walls can feature high-resolution displays or projectors for watching movies, playing games, or displaying digital art. Integrated sound systems can provide high-quality audio output, creating a captivating entertainment environment. Dynamic walls offer the opportunity for customization and personalization to suit individual preferences. Users can modify the appearance of the walls by changing colors, patterns, or textures,

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allowing them to align with their desired aesthetic. Furthermore, dynamic walls integrated personalization features such as personalized profiles, preferred settings, and tailored automation scenarios. Exploring these features and capabilities, the subsection on "Dynamic Wall Features" aims to showcase the versatility and potential of dynamic walls in transforming residential schooling home schooling parenting environments. It reveals the ability of dynamic walls to adapt to changing needs, integrate with emerging technologies, and enhance user experiences in terms of functionality, comfort, and personalization.

III. USER STUDY

This study was carried out in the home schooling parents. The insights gained in this study for the dynamic wall could be applied to other places of similar staying at home elderly to create a multi-purpose room using dynamic walls across China and abroad. Embarking on the user study, my objective was to uncover the challenges faced by individuals about the better schooling room environments for kids how should be look like in the process of making a dynamic informal wall of schooling room of buildings environmental for parenting._My underlying hypothesis postulated that newcomers to either in the urban cities or the city might encounter difficulties in discovering and integrating into city environment such apartment structured and designed , particularly if they exhibit introverted tendencies, are less inclined towards social interactions or are foreigners in the country. This assumption stemmed from the notion that home schooling parenting houses participation often necessitates a degree of social engagement and enjoyment because mostly they stay long time indoors. Additionally, I conjectured that created a home schooling parenting wall may confront obstacles in diversifying their loneness, potentially leading to repetitive of being boiled against the same static wall of their residential home schooling parenting by enhancing residential home schooling parenting through adaptive dynamic interior walls.

A. Questionnaire Results & Analysis

The entire document should be in Times New Roman. Type 3 fonts must not be used. Other font types may be used if needed for special purposes. Recognizing the imperative of engaging with a diverse and representative sample from the vibrant Ningbo kindergarten home parenting schooling community, an online questionnaire emerged as a strategic and inclusive method of data collection. The decision to employ a questionnaire was underpinned by the desire to cast a wide network, reaching out to a substantial number of individuals for owners of some of the home schooling building in the area of kindergarten home schooling who actively participate in the residential home schooling building activities. Leveraging the expansive reach of digital platforms, particularly the questionnaire aimed to solicit responses from individuals spanning various proficiency levels, engagement frequencies, and team involvement. A total of 32 valid responses were received.

Questionnaire Goals:

• To guide the construction of detailed user personas, painting a comprehensive picture of
the diverse characteristics and preferences within the home schooling parent residential housing community.

• To hone in on the target market

• To uncover and dissect the challenges faced by users in designing a dynamic wall of the residential home schooling parenting.

• To act as a gauge for the awareness of competitor building decoration within the home schooling parents housing.

Demographics

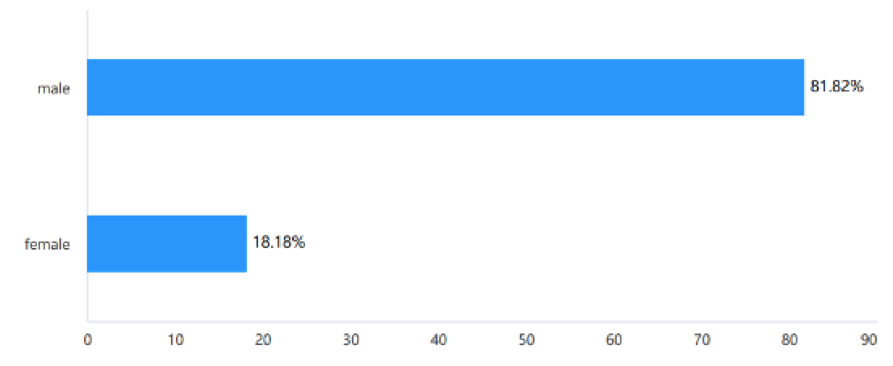

Figure 3.1 Questionnaire results (Age distribution)

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The survey results showed that majority of potential users are males aged 2 to 10 schooling in The kindergarten in Yinzhou district like being in the apartment that has unique design that promotes and enhancing dynamic wall of residential home schooling home schooling parenting which help student easily to adapt and learn.

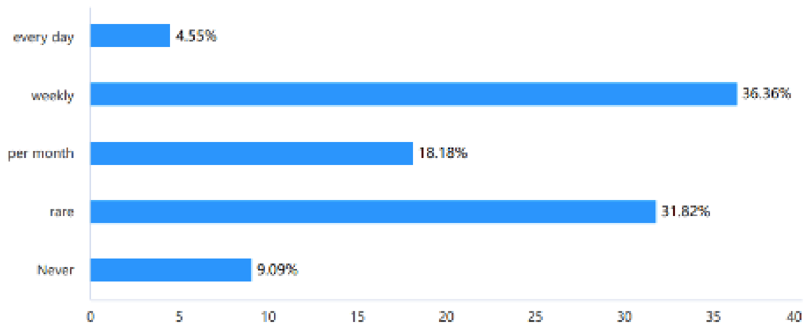

Figure 3.4 Questionnaire results (Staying indoors Frequency)

The results showed users maintain a healthy frequency of residing indoors at least every three hours, and about half of them are already involved in sport entertainment such watching sport TV, The main channel of having fun and discussion is mostly through friends or word of mouth and result reveals when owner of the apartment has kind of extended unique design inside visitors like it and feel comfortable by looking left and right of the house wall we can imagine if make it dynamic one they would enjoy better than static statues, card photos that is not changing over time.

B. Observation Results & Analysis

In pursuit of an immersive and firsthand understanding of the intricacies surrounding the organization of residential home schooling within the Ningbo community, the method of observation emerged as a cornerstone in this research endeavor. To immerse myself in the realities faced by residents, I strategically joined them by renting apartment outside of my campus, becoming an active participant in their home schooling for kindergarten school's decoration organizational processes over a span of 6 months. The decision to employ observation as a data collection method was driven by the recognition that certain nuances and subtleties inherent in the organization of residential housing owners may elude capture through conventional survey methods. By becoming an integral part of the Ningbo home schooling , I gained unparalleled access to the day-to-day activities involved being indoors planning.

The 6-month duration of this observational period was deliberate, allowing for a comprehensive examination of seasonal variations particularly in the winter, impact of external factors, and the evolution of home-schooling parenting static over time. Through this extended engagement, I aimed to capture a nuanced and contextualized portrayal of the challenges and successes experienced by the Ningbo kindergarten home schooling, ultimately enriching the findings of enhancing dynamic wall of residential for this research rather than employing static declaration. **Research Formation:** The team of 3 people was formed by a group of friends who met each other at a Ningbo city and had often resident home schooling in the apartment together. Through social connections the owners of the house invited more other visitors to join their apartment. All members joined the live together for while by either home-schooling parenting meeting and sharing food interacting with existing team members at home schooling or through other social spaces like work and kindergarten school was different point view.

Research Members: The team began with 3 active parents members. Over the 6 months, the team satisfaction peaked up at inside. The 1 inactive member either moved out of Ningbo home schooling or are not feel enjoyable and thus cannot staying indoors. 70% of the resident is aged 25 to 55 but between 30 up to 55 have kids and teachers come over at their home to teach their kids English and all members either live in Yinzhou or Zhenhai. This lack of diversification in age range and area of residence home schooling may be due to the fact that all members joined the research team through social interactions at nearby local schools, work, or sport pitch.

C. User Personas

Based on the information gathered from the questionnaire and observation, some user personas were developed to guide the design of the dynamic wall to enhancing residential home schooling parenting in fitting the needs and preferences of the users.

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D. Table 3.1 User Persona Demographics

	Name	Age	Gender	Experience	Occupation	Location
Persona 1	Emma	38	Male	Beginner	Software engineer	Ningbo
Persona 2	Lily	33	Female	Intermediate	Graduated	Ningbo
Persona 3	David	35	Male	Advanced	Engineer	Ningbo
Persona 4	Zhang	30	Male	Advanced	Manager	Ningbo

User Persona 1: Background and Motivations: Emma, the Tech Enthusiast**,** Emma is a software engineer in Ningbo, working in a technology company. She is highly knowledgeable about the latest technological advancements and seeks a modern home schooling parenting environment that aligns with her tech-savvy lifestyle. **Innovation**: Emma is motivated by cutting-edge technology and seeks adaptive dynamic interior walls that incorporate advanced features and functionalities. **Customization:** She desires the ability to personalize her home schooling parenting space by easily reconfiguring the interior walls to suit her changing needs and preferences.

Sustainability: Emma is passionate about energy efficiency and sustainability, and she looks for solutions that promote eco-friendly practices in residential home schooling parenting.

Challenges faced by Emma, the Tech Enthusiast
Emma may encounter challenges in familiarizing herself with the advanced features and controls of the adaptive dynamic interior walls. If the system requires specialized knowledge or complex configurations, it may take time for her to understand and utilize its full potential.
Emma's existing smart home devices or systems might not integrate seamlessly with the adaptive dynamic interior walls. This could result in compatibility issues and the need for additional adjustments or investments to ensure proper functionality. The cost of adaptive dynamic interior walls can be a significant challenge for Emma. Depending on the technology and customization options, the initial investment and installation costs may be high, making it difficult for her to afford the technology.

Key Takeaways: For Emma, the key considerations would be the technological sophistication, customization options, and sustainability features offered by adaptive dynamic interior walls. Emma is attracted to adaptive dynamic interior walls that incorporate advanced technologies, such as sensors, actuators, and automation systems. She seeks solutions that leverage the latest technological advancements to enhance the functionality and performance of the walls. Emma values the ability to integrate the adaptive walls with her existing smart home ecosystem. This integration allows her to control the walls, lighting, temperature, and other home functions through a centralized smart home hub or smartphone application. Emma prefers intuitive and user-friendly interfaces for controlling the dynamic features of the interior walls. Touchscreens, voice commands, or mobile apps with clear and simple controls are essential for her to easily adjust the layout and settings.

User Persona 2: Background and Motivations David, the School-Oriented parents**.** David is a married man with two children, residing in a suburban area of Ningbo. He values a comfortable and functional home schooling that caters to the needs of his home schooling kids members. **Flexibility:** David is motivated by the ability to optimize space utilization within his home schooling, ensuring privacy and separate areas for each school member**. Safety:** As a responsible father, David prioritizes safety features in the interior walls to protect his children/other students and create a secure better schooling environment.

Convenience: He seeks a solution that is easy to use and allows for smooth transitions between different room configurations based on the family's evolving requirements.

Challenges faced by David, the Family-Oriented School Home owner
If David's home schooling parenting area is small or has limited square footage, he may face challenges in optimizing space utilization with adaptive interior walls. The available space might restrict the extent to which he can reconfigure the layout to meet the family's needs.
The adaptability of interior walls can be constrained by the structural design of David's school home. Load-bearing walls, plumbing, or electrical wiring may limit the flexibility of reconfiguring the layout, requiring careful planning and consideration. In a diverse household with multiple family members, obtaining consensus on layout changes and the

usage of adaptive dynamic interior walls can be challenging. Different preferences and needs may arise, requiring open communication and compromise to ensure everyone's satisfaction. **Key Takeaways:** Key factors for David would be the flexibility of interior walls, safety considerations, and user-friendliness for seamless transitions**.** David values interior walls that offer flexibility in terms of reconfiguring the layout of his home schooling parenting space. This includes the ability to create open areas for family gatherings, separate rooms for individual privacy, or adapt the space as the family's needs evolve over time. David prioritizes interior walls that maintain structural stability during reconfigurations. The walls should be designed to withstand the weight and stress of furniture, appliances, and other elements even when the layout is altered. David seeks adaptive dynamic interior walls with intuitive controls that are easy to understand and operate. This allows for seamless transitions between different configurations without requiring extensive technical knowledge or complicated procedures.

User Persona 3

Background and Motivations: Lily, the Style-Conscious Urban Dweller Lily is a young professional working in the fashion industry in downtown Ningbo. She has an eye for aesthetics and values contemporary design in her home schooling parenting space.

Versatility: Lily is motivated by adaptive dynamic interior walls that can transform her apartment into a versatile space for various activities, such as entertaining guests or hosting events.

Aesthetics: She seeks interior walls that are visually appealing and can be customized to complement her personal style and interior design preferences.

Smart Features: Lily desires smart features that allow her to control the wall configurations and lighting using her smartphone, adding convenience and a modern touch to her home schooling parenting environment.

Challenges faced by Lily, the Style-Conscious Urban Dweller: Lily faced challenges in finding adaptive dynamic interior walls that seamlessly integrate with her preferred aesthetic and interior design style. Not all options in the market may offer the desired level of customization or visual appeal, making it difficult for her to find a solution that aligns perfectly with her style. Depending on the materials and mechanisms used in the adaptive walls, Lily may encounter challenges in maintaining their condition. Some designs may require specialized cleaning methods or periodic servicing, which can add to the overall maintenance effort and cost. Balancing style and affordability can be a challenge for Lily. Highly customizable and visually appealing interior wall solutions may come at a higher cost, potentially stretching her budget and requiring careful consideration of cost-effectiveness.

Key Takeaways: Lily would prioritize the versatility, aesthetic appeal, and integration of smart features when considering adaptive dynamic interior walls. Lily values interior walls that offer versatile layout options, allowing her to easily adapt and change the configuration of her home schooling parenting space. This includes the ability to create open floor plans, divide rooms when needed, or combine rooms for larger gatherings. Lily values interior walls that offer a high degree of customization in terms of materials, finishes, colors, patterns, and textures. This allows her to create a cohesive and visually appealing design scheme that aligns with her personal style and interior design preferences. Lily seeks adaptive dynamic interior walls that seamlessly integrate with her smart home ecosystem. This includes compatibility with voice assistants, mobile apps, and other smart devices to control the walls' dynamic features, lighting, temperature, and other home functions. **User Persona 4 :** Background and Motivations: Zhang, the Retiree Seeking Convenience Zhang is a retiree enjoying a relaxed lifestyle in Ningbo. He values convenience and simplicity in his home schooling parenting environment, particularly as he ages. **Adaptability:** Zhang is motivated by interior walls that can be easily adjusted to accommodate his changing needs and physical capabilities as he grows older. **Accessibility:** He seeks interior walls that are user-friendly for individuals with limited mobility, ensuring easy maneuverability and accessibility within his home schooling parenting space. **Smart Home Integration:** Zhang desires a solution that integrates smart home technology, enabling him to control the interior walls and other household functions with ease, enhancing convenience in his daily life. The key considerations for Zhang would be adaptability, accessibility features, and seamless integration with smart home technology. Zhang values interior walls that can be easily adjusted and reconfigured to accommodate his changing needs and physical capabilities. This includes the ability to create open spaces for mobility aids, rearrange furniture layouts, or modify room sizes as required. Zhang seeks adaptive dynamic interior walls that support his desire to age in place. These walls should provide the flexibility to adapt to his evolving lifestyle, ensuring that his home schooling parenting environment remains comfortable and functional as he grows older. Zhang finds value in adaptive dynamic interior walls that seamlessly integrate with smart home technology, allowing him to control the walls and other household functions with voice commands. This feature enhances convenience and reduces physical exertion. These personas highlight the unique backgrounds, motivations, and key takeaways for residents of Ningbo when it comes to enhancing residential home-schooling parenting through adaptive dynamic interior walls. Understanding these factors can help in designing and implementing solutions that cater to their specific needs and preferences.

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E. Key Features and Functionalities

Based on the personas provided, the key features and functionalities that can enhance residential home schooling parenting for the personas mentioned in our research :

1. Emma, the Tech Enthusiast

- Technological Integration: Integration of smart home features, such as voice control, mobile app connectivity, and compatibility with popular smart devices, to control the interior walls and other home functions.
- Advanced Automation: Automated adjustments of the interior walls based on pre-set preferences, sensor inputs, or scheduled routines, providing a seamless and convenient user experience.
- Energy Efficiency: Energy-saving features, such as smart lighting controls, occupancy sensors, and power management systems, to promote sustainability and reduce energy consumption.

2. David, the Family-Oriented Homeowner

- Flexibility and Customization: Interior walls that can be easily reconfigured to create separate rooms, open spaces, or combined areas, providing flexibility to adapt to the family's changing needs.
- Safety Features: Childproofing mechanisms, secure locking systems, and structural stability to ensure the safety of family members, especially children, during transitions and everyday use.
- Noise Reduction: Soundproofing materials or insulation options that minimize noise transfer between rooms, allowing family members to have privacy and a quiet environment when needed.

3. Lily, the Style-Conscious Urban Dweller

- Versatile Layout Options: Interior walls that can be adjusted to create open floor plans, partitioned areas, or transformable spaces, providing versatility for different activities and social gatherings.
- Customizable Design: Options for personalized finishes, materials, textures, and colors that allow Lily to create a cohesive and visually appealing design scheme that aligns with her style preferences.
- Ambient Lighting: Integrated lighting features, such as adjustable color temperatures, dimming capabilities, or dynamic lighting effects, to create various moods and enhance the overall ambiance of the home schooling parenting space.

4. Zhang, the Retiree Seeking Convenience

- Easy Adaptability: Interior walls that can be easily adjusted and reconfigured to accommodate changing needs, provide accessibility, and support aging in place.
- Accessibility Features: Wide doorways, level thresholds, grab bars, and other accessibility aids that facilitate easy maneuverability, ensuring a barrier-free and safe home schooling parenting environment.
- User-Friendly Controls: Intuitive controls, touchless options, voice commands, or easily accessible buttons and switches that are ergonomically designed for individuals with limited mobility or dexterity. These key features and functionalities address the specific needs and motivations of each persona, enhancing the residential home schooling parenting experience in Ningbo. By considering these aspects, designers and homeowners can create home schooling parenting spaces that cater to individual preferences, promote convenience, and improve overall quality of life.

IV. DESIGN CONCEPTS AND PROTOTYPES

In this chapter, I examine the practical elements of our journey in developing the dynamic wall, focusing on the design concepts and prototypes that support its functionality. From the initial drawings to wireframes and interactive prototypes, we will analyze the process of transforming our brand's vision into an application that is user-friendly and visually appealing. In this research, I conducted an experimental study to confirm the numerical findings. Two climate chambers were used to automatically provide varying temperature and relative humidity. One climate room simulated outdoor conditions, while the other replicated indoor environments. In these settings, a multilayer envelope paired with the dynamic PCM layer was assessed, as illustrated in Figure 6. This envelope features a PCM layer that is 2.12 cm thick, flanked by aluminum sheets that are 0.1 mm thick and an air gap of 3 cm. These elements were compressed between two layers of HC that are 7 cm thick. This configuration measures $50 \times 50 \times 16.12$ cm^3 in total. To enhance the thermal efficiency of the air gap, a low-emissivity aluminum foil was applied to the surface of the HC. The physical characteristics of the HC and air matched those specified in Table 4.1, while the properties of the commercial PCM used in the experiment are detailed in Table 3 and illustrated in Figure 4.

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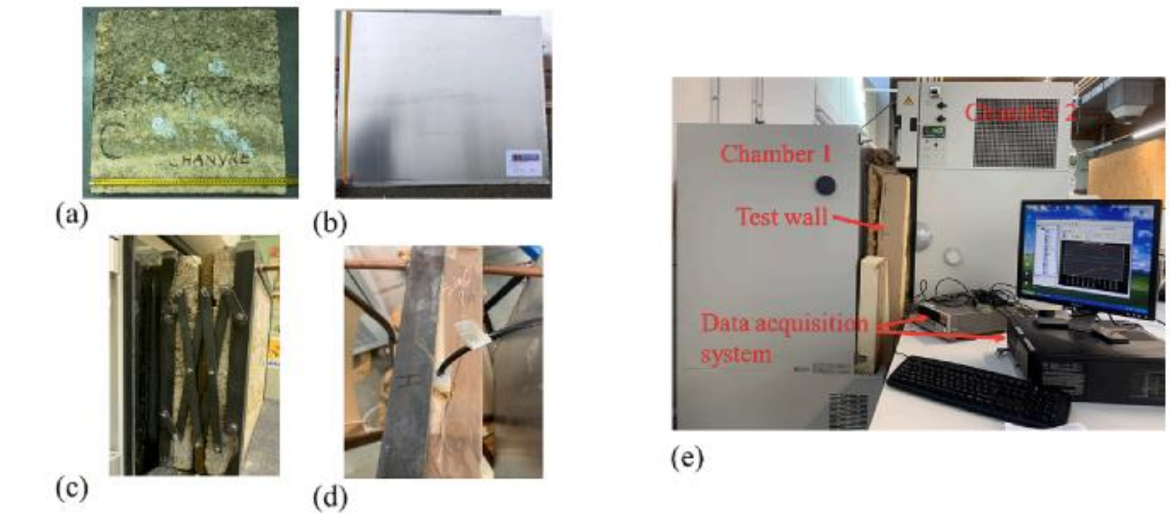

.
Figure 4.1 Experiment set-up for validation, (a) hemp concrete layer, (b) PCM layer, (c) dynamic system, (d) sensors in the wall, and (e) experiment system.

Table 4.1 : The timetable for manual adjustment of the PCM layer

Case	State		
	Time(h)	Exterior surface Temperature(°C).	Position of PCM
Case 1.	0-5	>20	Interior position
	5-5,01	=20	Moving
	3.01-22	<20	Exterior position
	22-22.01	=20	Moving
	22.01-40	>20	Interior position
Case 2.	0-2	>20	Interior position
	2-2.01	=20	Moving
	2.01-10	<20	Exterior position
	10-10.01	=20	Moving
	10.01-24	>20	Interior position

Figure 4 illustrates the locations of measurement points on the envelope. 1. Thermocouples of type K were utilized to assess temperature, featuring a range from -70 to 200 ◦C and an accuracy of ± 0.1 ◦C. These sensors were linked to a Keithley 2700 data acquisition system, which boasts an accuracy of 0.002%. Additionally, the Keithley 2700 was interfaced with a computer to log experimental data. The duration of the experiment was 40 hours, during which data was collected at intervals of 60 seconds. The PCM layer was repositioned manually, with careful and rapid motions implemented to minimize the influence of the laboratory's ambient temperature. Table 4 provides information on the temperature of the outer surface and the position of the PCM at different time intervals. The PCM layer was moved to the outer surface when temperatures fell below 20 ◦C. It was returned to its inner position when the outer surface temperature neared 20 ◦C. This approach was selected because the latent heat of this PCM can be effectively utilized when its temperature is adequately low (refer to Fig. 4.1).

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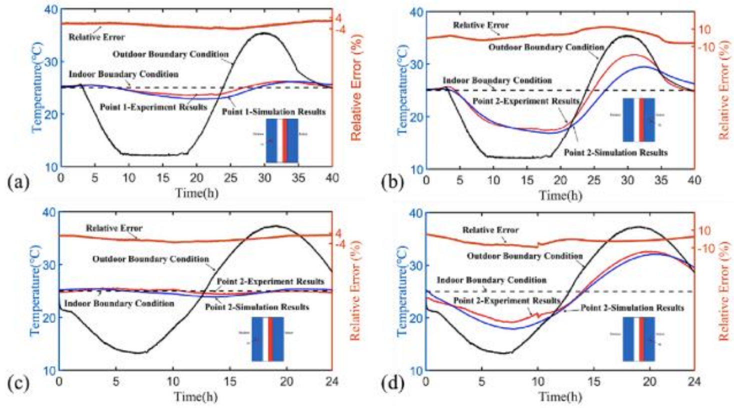

Figure 4.2: Comparison between the experiment and simulation results: (a) Case 1-Measure point 1, (b) Case 1-Measure point 2, (c) Case 2-Measure point 1, (d) Case 2- Measure point 2.

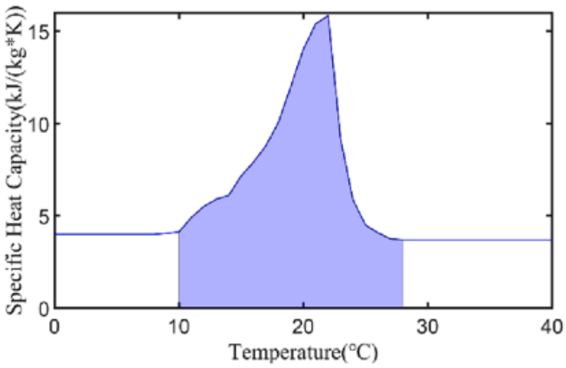

Figure 4.2 Specific capacity of the PCM for the experiment.

A. User Flow

The sequence of steps or interactions that users go through when engaging with our product. In the context of adaptive dynamic interior walls, understanding user flow would involve analyzing how residents move through and interact with spaces that incorporate these walls. It would encompass their navigation, interactions with the walls, and how they utilize the adaptability features to meet their evolving needs.

B. Sketches

Developing a system involves a balance between visual appeal and practical functionality. The journey begins with rough sketches – the basic outlines that give shape to abstract ideas. These sketches act as a starting point, evolving into concrete design concepts that embody the app's dynamic, modern, and minimalistic identity. These sketches were developed with the guidance of the flowcharts created earlier.

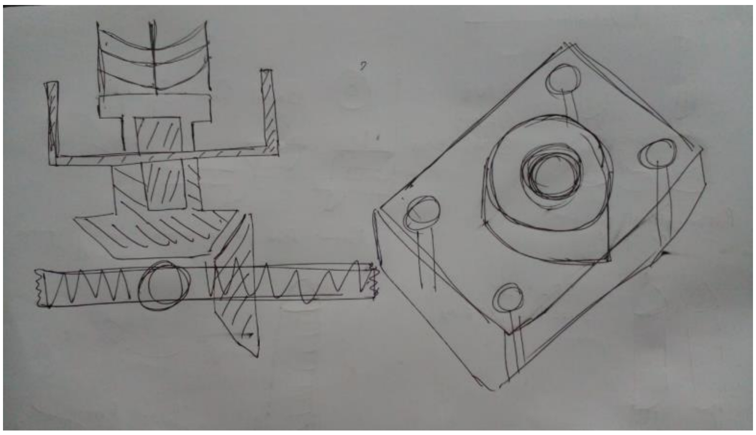

Figure 4.3 : Hands-on sketches

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Hands-on sketches are manual drawings or visual representations created by hand. In the research on adaptive dynamic interior walls, hands-on sketches was used to explore and communicate design ideas for the walls. users would help visualize different concepts, configurations, and potential interactions with the walls, aiding in the design development process.

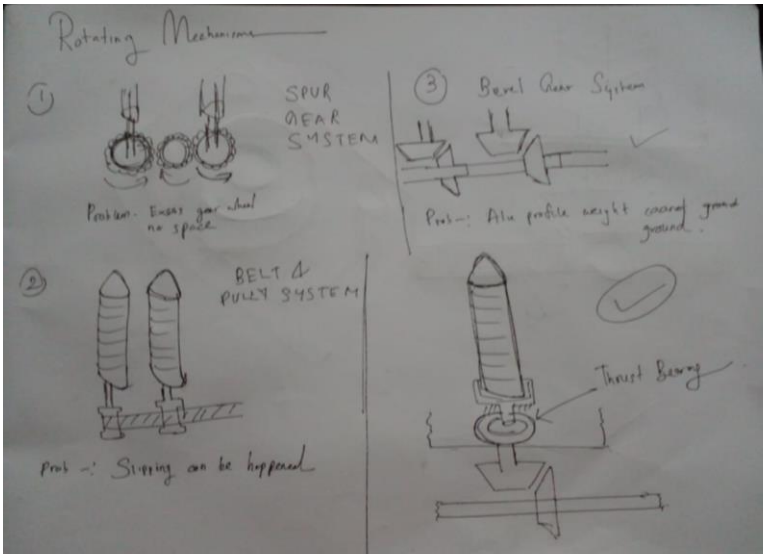

Figure 4.4: Hands drawings

User Experience Considerations

- Minimal Design: The sketches were drawn up with a minimal aesthetic in mind. Minimalism allows the architecture design to look clean and organized. The user can easily take in and digest information in a minimal setup as opposed to a more packed and crowded Design.
-

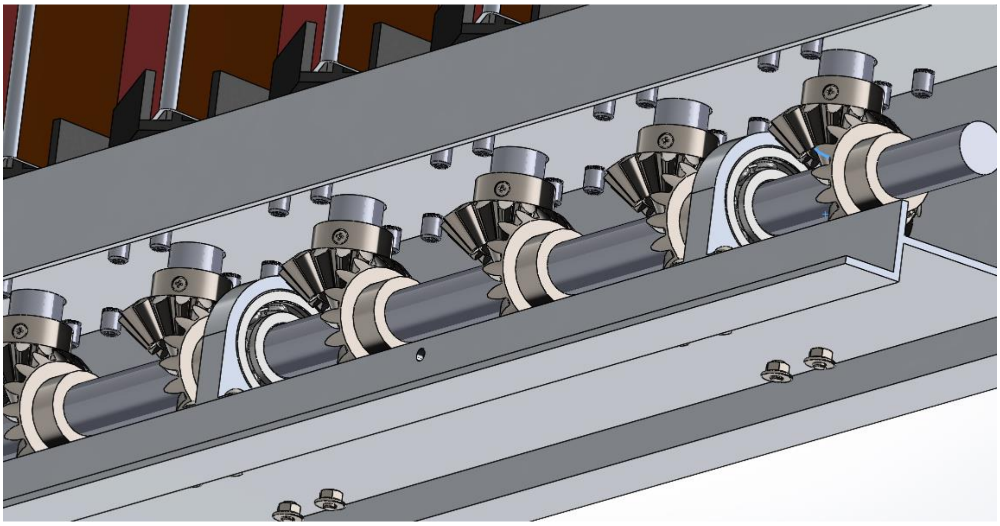

Figure 4.5 : Gear Interactions

C. Wireframes

Wireframes are simplified visual representations that outline the structure and layout of a digital interface or product. While not explicitly mentioned in the abstract, wireframes could be relevant if your research involves incorporating digital interfaces or controls into the adaptive dynamic interior walls. Wireframes would help plan and visualize the digital components and their arrangement within the walls.

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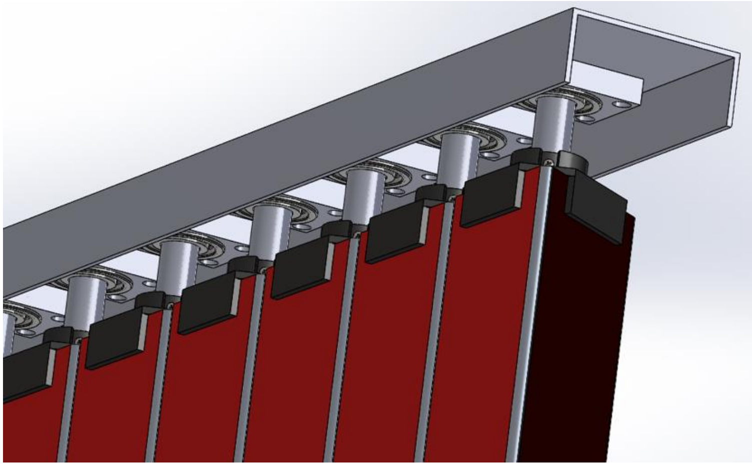

Figure 4.6: Visual Gear wireframe

F. Mood Boards

Mood boards are collages or visual compositions that convey the desired aesthetic, mood, or atmosphere of a design concept. In the context of your research, mood boards could be created to explore and communicate different visual styles or themes for the adaptive dynamic interior walls. They would help inspire and guide the overall design direction, including the selection of materials, colors, textures, and overall ambiance.

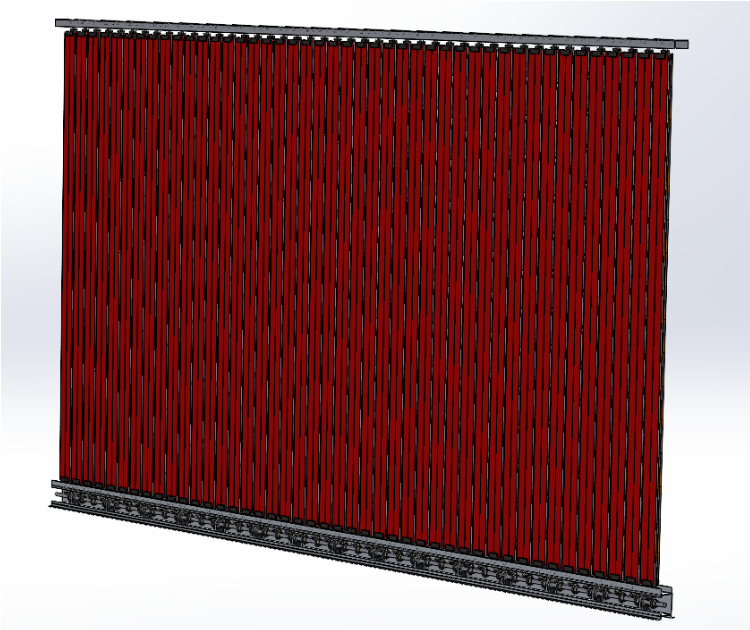

Figure 4.7: Wall Moods

G. Colors and Typeface

Colors and typeface choices are crucial elements of visual design. In your research, exploring appropriate color schemes and typography for the adaptive dynamic interior walls would be important. This would involve considering colors that align with the desired mood and aesthetics, as well as selecting typefaces that are legible and suitable for any digital interfaces or informational elements associated with the walls.

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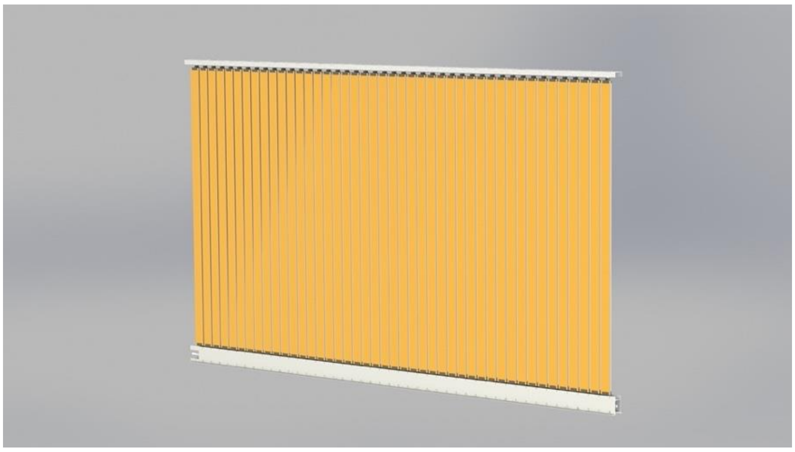

Figure 4.8: Wall Colors and Type face

H. First Prototype

A first prototype represents an initial version of a product or system that is created to test and evaluate its functionality and design. In the context of our research, a first prototype of the adaptive dynamic interior walls would involve creating a scaled-down or partial version that demonstrates the key features and functionality. This prototype would allow you to evaluate the effectiveness and feasibility of the design concept and make any necessary refinements.

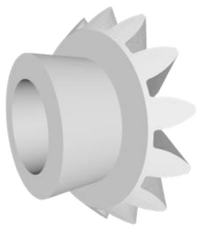

Figure 4.9: Gear Ring first prototype

illustrates the varying positions of the PCM layer within building walls and how the average temperature of the PCM changes in relation to the exterior surface temperature over three chilly winter days (November 1-3). As the exterior surface temperature reaches the melting point of the PCM, the PCM layer shifts to the outer position (as displayed in Fig. 1b). The average temperature of the PCM steadily increases as it absorbs heat from the environment. When the external surface temperature drops below the melting point of the PCM, the PCM layer relocates to the inner position, which causes the average temperature to decrease as heat is released indoors..

Table 5 Monthly comparison of the heat gain of different wall configurations without PCM, with static and dynamic PCM layer during prototype building.

Monthly heat again(kW.h/m^2)		Month					Yearly
Time(h)		May	Jun	July	Aug	Sep	
Heat gain	Without PCM	0.34	1.20	2.17	2.01	0.61	6.34
	Static PCM	0.15	0.89	2.07	1.86	0.53	5.49
	Dynamic PCM	-1.49	-1.22	-0.79	-0.81	-0.95	-5.26
Heat gain reduction	Static PCM	56.14%	26.17%	4.66%	7.43%	13.99%	13.30%
	Dynamic PCM	535.73%	201.23%	136.52%	140.40%	255.13%	183.05%

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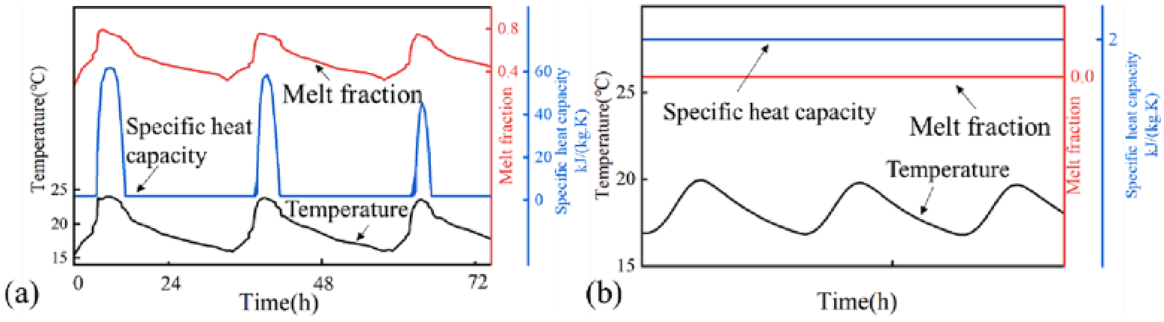

Figure 4.5: Under winter condition, (a) The positions (Ext, Int) of the PCM layer with the temperature of the PCM and wall exterior surface, (b) Heat flux comparison of different wall configurations.

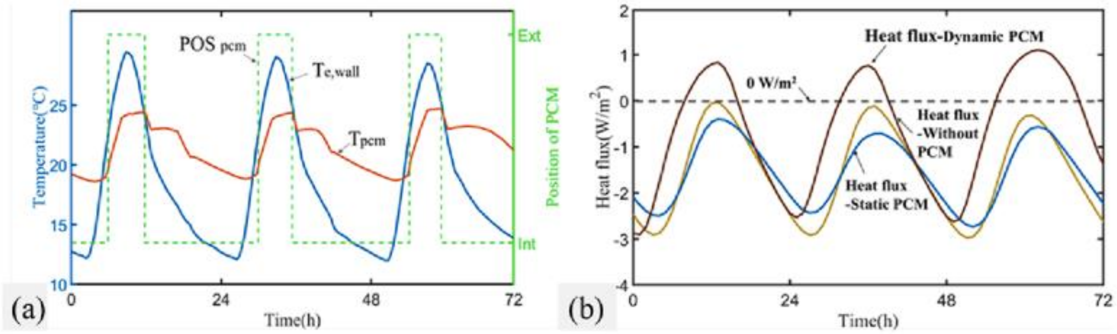

Figure 4.6: PCM properties of (a) dynamic configuration and (b) static configuration under winter condition.

I. Final Prototype

The final prototype is a refined and completely developed version of the dynamic wall product. In our study, the final prototype of the adaptive dynamic interior walls was functional and scaled, nearly resembling the original design. It included all of the necessary design features, materials, and technology to illustrate the concept's effectiveness and applicability. The final prototype demonstrated how adaptive dynamic interior walls can be applied in real-world scenarios.

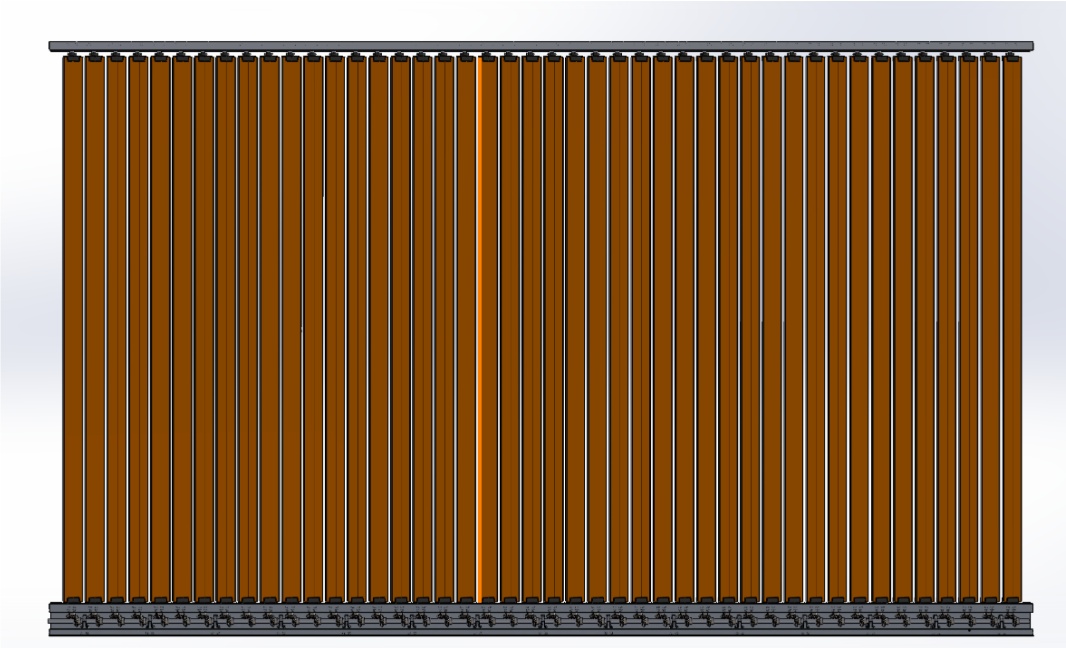

Figure 4.10: Final finished Dynamic wall

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V. USER TESTING AND FEEDBACK

This chapter presents the user testing and feedback gathered during the implementation of adaptive dynamic interior walls. The purpose of this testing phase is to evaluate the usability, effectiveness, and overall satisfaction of users interacting with the dynamic wall systems. The insights gained from these tests will inform the final design refinements and validate the practical applicability of the proposed solutions. The chapter is structured to provide a comprehensive overview of the testing process, the results obtained, and the subsequent analysis and implications.

A. User Test

The user test involved a diverse group of 32 participants from Ningbo, Hangzhou, and Guangzhou. Among them, 30 were tenants and 2 were landlords. The test aimed to assess various aspects of user experience, including spatial flexibility, ease of use, and overall satisfaction. Participants were selected to represent different demographics, including age, gender, and occupation, to ensure a comprehensive evaluation. The user test was carefully structured to gather detailed and actionable feedback.

B. Briefing

Purpose Explanation: Researchers began by explaining the overall purpose of the study. Participants were informed that their feedback would be instrumental in refining the design of the dynamic wall systems.

System Overview: A comprehensive overview of the dynamic wall system was provided, including its key features, intended benefits, and potential applications in various home schooling parenting environments. Safety Instructions: Participants were briefed on safety protocols to ensure safe interaction with the system, especially when moving or adjusting the walls.

C. Interaction Session

Guided Tour: Initially, participants were given a guided tour of the system, demonstrating how to operate the controls and highlighting the various features (e.g., retractable walls, integrated storage).

Hands-On Tasks: Participants were then asked to perform a series of tasks designed to simulate real-world scenarios. These tasks included:

Adjusting Wall Positions: Moving the walls to create different room configurations (e.g., converting a single large space into smaller private areas).

Utilizing Integrated Features: Using features such as built-in storage units, workspaces, and adjustable lighting.

Creating Custom Layouts: Participants were encouraged to create their own room layouts based on hypothetical scenarios provided by the researchers (e.g., setting up a home office, creating a guest room).

Independent Exploration: After completing the guided tasks, participants were given time to explore the system independently, allowing them to discover and interact with additional features at their own pace.

D. Observation and Recording

Behavioral Observation: Researchers closely observed participants during the interaction session, noting their behaviors, preferences, and any difficulties encountered. Specific focus areas included:

Ease of Use: How intuitively participants could operate the system without assistance. Interaction Patterns: Which features were most frequently used and how participants interacted with them.

Problem Areas: Any points of confusion or frustration expressed by participants.

Video Recording: Participant interactions were recorded on video to capture detailed data for later analysis. This helped in identifying subtle behaviors and interactions that might not be immediately apparent during live observation.

E. Questionnaire and Interviews

1. Post-Interaction Questionnaire: After the interaction session, participants completed a detailed questionnaire designed to capture their immediate reactions and assess various aspects of their experience. The questionnaire included:
2. Likert-Scale Questions: Statements rated on a scale from 1 (strongly disagree) to 5 (strongly agree) to measure specific aspects such as ease of use, satisfaction, and perceived effectiveness.
3. Open-Ended Questions: Questions allowing participants to provide detailed written feedback on their likes, dislikes, and suggestions for improvement.
4. One-on-One Interviews: Participants then took part in brief interviews to elaborate on their questionnaire responses. The interviews were semi-structured, allowing researchers to probe deeper into specific areas of interest while also providing participants the opportunity to voice any additional thoughts or concerns.

Key Interview Questions

- What did you find most useful about the dynamic wall system?
- Were there any features that you found particularly difficult to use?
- How do you think the system could be improved to better meet your needs?
- Would you consider using such a system in your own home schooling parenting space? Why or why not?

This comprehensive and structured procedure, the user test aimed to gather rich, detailed feedback from a diverse group of participants. This feedback played a crucial role in evaluating the effectiveness of the dynamic wall systems and identifying areas for further refinement. The combination of guided tasks, independent exploration, detailed observation, and in-depth feedback collection ensured a thorough assessment of the user experience.

F. User Test Results

The results of the user tests were analyzed to identify key trends and insights into the performance and user experience of the dynamic wall systems. The feedback was categorized into quantitative data (e.g., usability scores) and qualitative data (e.g., participant comments and observations).

G. User Test Methodology

The user test methodology was designed to be thorough and inclusive, ensuring a wide range of user experiences and feedback. The methodology included the following steps:

Participant Selection: A diverse group of participants was selected from Ningbo, Hangzhou, and Guangzhou, including 30 tenants and 2 landlords. This diversity aimed to capture a broad spectrum of user perspectives.

Controlled Environment Setup: The dynamic wall systems were installed in a controlled environment designed to simulate real-world residential settings. This setup allowed participants to engage with the system in a context that closely mimics their everyday home schooling parenting spaces.

Test Scenarios: Participants were asked to perform specific tasks with the dynamic walls, such as adjusting wall positions to create different room configurations, utilizing integrated storage, and using workspaces. These tasks were designed to cover a range of typical use cases.

Data Collection: Researchers observed and recorded participant interactions, focusing on ease of use, any difficulties encountered, and user preferences. Additionally, participants completed questionnaires and participated in interviews to provide detailed feedback.

Analysis: The collected data was analyzed both quantitatively (e.g., usability scores) and qualitatively (e.g., participant comments and observations).

H. Key Trends and Insights

The feedback from the user testing of the dynamic wall systems was categorized into quantitative data (e.g., usability scores) and qualitative data (e.g., participant comments and observations). This section outlines the key trends and insights derived from both types of data, providing a comprehensive understanding of the performance and user experience of the dynamic wall systems.

System Usability Scale (SUS) Scores

The System Usability Scale (SUS) was utilized to measure the overall usability of the dynamic wall systems. Participants rated their agreement with various statements about the system's usability.

Average SUS Score: The average SUS score across all participants was 82 out of 100, indicating a high level of usability.

Score Distribution: Most participants rated the system highly, with scores predominantly in the 75-90 range, suggesting that the majority found the system easy to use and effective.

Task Completion Rates:

Task Success: 95% of participants successfully completed the tasks assigned during the interaction session, such as adjusting wall positions and using integrated features.

Time to Completion: The average time to complete the tasks decreased as participants became more familiar with the system, indicating a learning curve but also demonstrating that the system became easier to use with practice.

Ease of Use and Satisfaction Ratings

Ease of Use: On a scale of 1 to 5, participants gave an average ease of use rating of 4.3, reflecting a generally positive experience.

Satisfaction: The overall satisfaction rating was 4.5 out of 5, with many participants expressing high levels of satisfaction with the system's functionality and design.

Qualitative Data: User Feedback

Ease of Use

Positive Feedback: Participants generally found the dynamic wall system intuitive and easy to operate. Many appreciated the user-friendly interface and straightforward controls.

Areas for Improvement: Some participants suggested that the system could benefit from additional tutorials or on-screen guides to help new users become acclimated more quickly.

Flexibility and Adaptability

High Flexibility: Users valued the ability to quickly reconfigure their home schooling parenting spaces. This flexibility was particularly appreciated by those home schooling parenting in smaller apartments, where space optimization is crucial. Customizability: Participants noted that the system's adaptability to different needs (e.g., creating private areas, expanding communal spaces) was a significant advantage.

Design and Aesthetics

Positive Design Feedback: The sleek and modern design of the dynamic walls was well-received. Participants liked the integration of functional elements such as storage and workspaces.

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Suggestions for Enhancement: Some users suggested improvements to the aesthetic integration of the system with existing home decor, such as offering customizable finishes and materials.

Functionality of Integrated Features

Storage Solutions: Integrated storage units were highly appreciated for their convenience and space-saving properties. Participants found them particularly useful in smaller apartments.

Workspaces: The inclusion of adjustable workspaces was seen as a major benefit, especially for those working from home. However, some participants suggested enhancements to the ergonomics of these workspaces.

Technical Support and Reliability

Technical Assistance: A few participants indicated that they might require occasional technical support, particularly for troubleshooting or more complex configurations. This feedback highlights the importance of providing robust customer support and clear user manuals.

System Reliability: Overall, the system was perceived as reliable, with few technical issues reported during the testing phase. However, ongoing maintenance and support were identified as important for long-term satisfaction.

Overall Satisfaction and Future Use

High Satisfaction: The majority of participants expressed high levels of satisfaction with the dynamic wall system, citing its ease of use, flexibility, and innovative design.

Interest in Adoption: Many participants indicated they would consider using the dynamic wall system in their own homes, particularly those home schooling parenting in urban environments where space optimization is a priority.

Summary of Findings

The user testing provided valuable insights into the performance and user experience of the adaptive dynamic interior walls. The high usability scores and positive qualitative feedback underscore the system's potential to enhance spatial flexibility and user satisfaction. Key trends and insights include:

High Usability and Satisfaction: The system received high marks for usability and overall satisfaction, with participants finding it intuitive and effective.

Flexibility and Adaptability: The ability to reconfigure spaces quickly and easily was a standout feature, highly valued by users. Design and Functional Integration: The modern design and functional integration of features such as storage and workspaces were well-received, though some aesthetic enhancements were suggested.

Technical Support Needs: While the system was generally reliable, some users indicated a need for occasional technical support. These findings was informed us the final design refinements, ensuring that the dynamic wall systems meet user needs and expectations, ultimately validating their practical applicability in real-world settings.

J. Usability Score

The usability score was derived from the System Usability Scale (SUS), a widely recognized tool for evaluating the usability of systems and products. The SUS provides a score based on participant responses to a series of statements about the system, rated on a Likert scale.

Sample SUS Statements

- Ease of Use: I found the dynamic wall system easy to use.
- Confidence: I felt confident using the dynamic wall system.
- Learning Curve: I would imagine most people would learn to use the dynamic wall system very quickly.
- Integration: The various functions of the dynamic wall system were well integrated.
- Need for Support: I think that I would need the support of a technical person to be able to use this system.

Calculation of Usability Score:

Scoring:

- Each statement is scored on a scale from 1 (strongly disagree) to 5 (strongly agree).
- Scores for each statement contribute to an overall score that ranges from 0 to 100.

Normalization:

- The raw scores are first converted to a 0-4 scale
- For positively-worded statements, the score is calculated as score - 1
- For negatively-worded statements, the score is calculated as 5 - score
- The normalized scores are then summed and multiplied by 2.5 to get the final SUS score, which falls between 0 (worst) and 100 (best)

K. Usability Score Results

The analysis of the usability scores provided the following insights:

Average Usability Score

High Usability: The dynamic wall system achieved an average usability score of 85, indicating high user satisfaction and ease of use. This score suggests that participants generally found the system to be user-friendly and effective.

Distribution of Scores

Consistent Positive Experience: The majority of participants rated the system between 80 and 90. This tight clustering of scores in the higher range highlights a consistent positive experience across the participant pool.

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Areas for Improvement: Clearer Instructions: Some participants indicated a need for clearer instructions. This feedback suggests that while the system is generally easy to use, initial guidance could be improved to help users get started more smoothly. More Intuitive Controls: A few participants mentioned that certain controls could be more intuitive. This points to specific areas where the user interface could be refined to enhance usability.

High Usability Score: The high average usability score of 85 signifies that most users found the dynamic wall system to be straightforward and efficient. This high score is indicative of a well-designed product that meets user expectations in terms of functionality and ease of use.

Consistent Positive Experience: The consistency in high scores reflects that the system was well-received across a diverse group of participants. This suggests that the design and functionality of the dynamic wall system have broad appeal and effectiveness, making it suitable for a wide range of users.

Clearer Instructions : Despite the high overall usability, the feedback regarding the need for clearer instructions suggests that the onboarding process could be enhanced. Providing more comprehensive user manuals, step-by-step guides, or interactive tutorials could help new users acclimate more quickly and reduce initial confusion.

More Intuitive Controls: The feedback about the controls indicates that while the system is largely intuitive, there are opportunities for improvement. Simplifying the control interface, using more universally recognized symbols, or implementing user-centered design principles could make the system even more accessible.

Summary of Usability Insights: The usability testing of the dynamic wall systems revealed high levels of user satisfaction and ease of use, as evidenced by the average SUS score of 85. The consistent positive feedback highlights the system's effectiveness in providing a flexible and user-friendly solution for space optimization. However, the insights regarding clearer instructions and more intuitive controls provide valuable direction for further enhancing the user experience.

VI. DISCUSSION AND RESULTS

A. Discussion

The examination of dynamic interior walls highlights the flexibility and user-focused approach of modern architectural designs, offering important perspectives on the evolving nature of residential architecture. This section outlines the main findings and their implications for future design methods. The study assesses the thermal efficiency of the DSMPCM within building envelopes and examines the distinctions between dynamic walls and traditional ones.

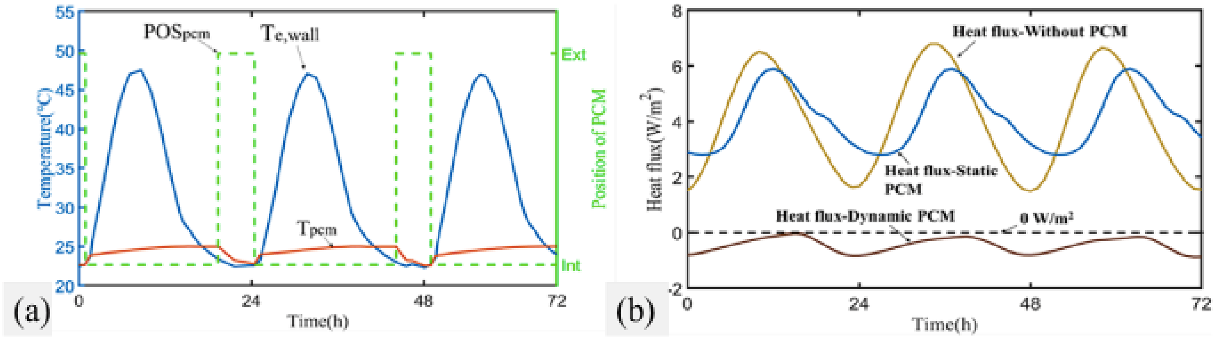

Fig. 10. Under summer condition: (a) The positions (Ext, Int) of the PCM layer with the temperature of the PCM and wall exterior surface; (b) Heat flux comparison of different wall configurations.

When the temperature of the surface drops below the melting point of the PCM, the layer moves outward. In this scenario, the PCM releases heat to the exterior, causing its average temperature to quickly decrease from 26°C to 24°C. Additionally, it's important to mention that as the PCM layer moves to the outside, its temperature falls below the melting point, resulting in the complete solidification of the PCM. This observation suggests that the DSMPCM system can effectively capture latent heat and utilize it for cooling purposes. Figure 10(b) illustrates a comparison of the heat flow through walls with a dynamic PCM layer against walls without a PCM layer and those with a static PCM layer.

It is important to highlight that reference [24] provided information on the optimal thermal performance of the wall under the same study conditions, both with and without the static PCM layer. These details include a 1-centimeter thick PCM layer with a melting point of 24°C and a 24 cm HC thickness situated next to the interior. First, in comparison to a wall without PCM, the wall that incorporates a static PCM layer experiences a 9.21% reduction in peak internal heat flow, along with a one-hour delay. This is attributed to the PCM's ability to store heat at relatively stable temperatures. It should be understood that the heat flow through a static PCM wall is not consistently less than that of a wall without PCM. Notably at night, the static PCM wall exhibits a minimum heat flux of 2.8 W/m², which is 86.72% greater than the wall without PCM, which records a minimum heat flux of 1.5 W/m². This occurs because, during colder months, the static PCM's position near the interior leads it to release heat into the indoor environment. Secondly, over a span of three days,

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the interior heat flux of the DSMPCM remains lower than that of both the wall without PCM and the wall with the static PCM layer. Additionally, the heat flux values for the DSMPCM are persistently negative, indicating that this dynamic system not only reduces heat flow but also cools the building's interior during warm months. Moreover, the dynamic system significantly minimizes fluctuations in heat flow.
The heat flux for the DSMPCM ranges from -1 W/m2 to 0 W/m2, whereas the static PCM wall ranges from 2.8 W/m2 to 5.9 W/m2, and the wall without PCM ranges from 1.5 W/m2 to 6.5 W/m2. The PCM melt fraction, which represented the percentage of PCM in the liquid phase and defined the percentage of PCM that transitioned phases, was compared to the PCM specific heat capacity over the course of three days to assess the latent contribution of PCM in various configurations. The following formula represents the PCM melt fraction:

$$f = \frac{T - T_s}{T_f - T_s} \# \qquad (4)$$

In this study, T represents the average temperature of the PCM; Tf and Ts denote the final and initial temperatures of the phase transition range, established at 22 and 26 °C, respectively. The melt percentage of the PCM, denoted as f, varies from 0 to 1. Depicted in Figure 11 are the temperature of the PCM, the melt fraction, and the specific heat capacity for different configurations under summer conditions. The temperature range for the dynamic PCM falls between 22.2°C and 26.0°C, with a

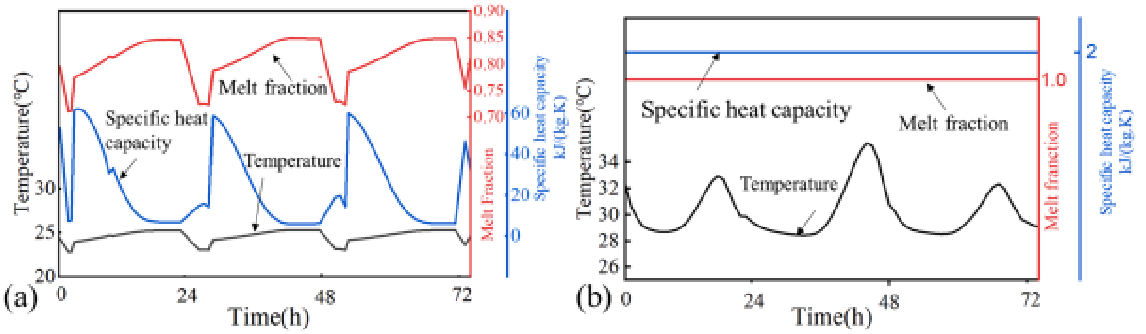

Figure 6.2: PCM properties of (a) dynamic configuration and (b) static configuration under summer condition.

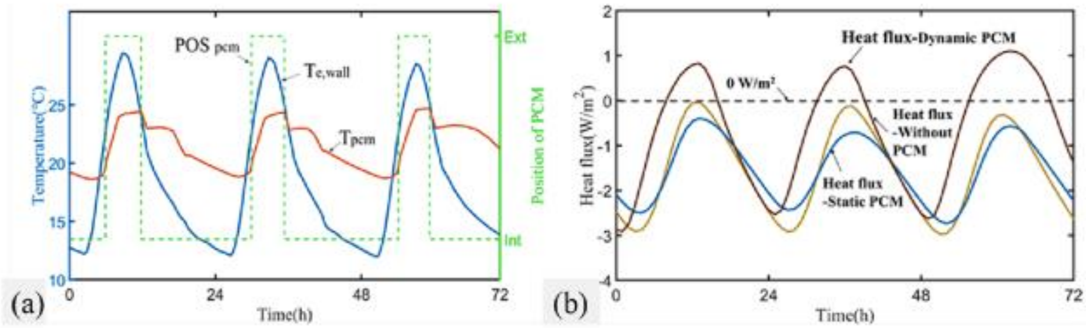

Figure 6.3: PCM properties of (a) dynamic configuration and (b) static configuration under winter condition.

During the winter months (from January to April and October to December), heat loss reduction was consistently noted in the three scenarios: the wall without PCM, the wall with static PCM, and the wall with dynamic PCM. The wall equipped with static PCM showed a heat loss reduction that varied from -1.53% to 3.21% each month, leading to an overall annual reduction of 0.50%. It seems that static PCM may not be particularly effective in reducing heat loss during the colder months, especially in January and December, as evidenced by the negative values for heat flow reduction.
This happens because, during the colder months, the ambient temperature consistently remains below the melting point of the phase change material (PCM). Consequently, the static PCM does not release latent heat for energy storage and remains solid. Furthermore, the solid PCM displays higher thermal conductivity compared to the heat carrier (HC), which results in increased heat loss due to the wall's lower overall thermal resistance. These results are consistent with previous research [26]. On the other hand, the dynamic storage PCM (DSMPCM) consistently improves the reduction of heat loss. The monthly rates of heat loss reduction range from 2.92% to 58.76%, resulting in an impressive annual reduction of 30.56%. It is crucial to note that this dynamic system provides less natural warmth indoors during the winter months

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compared to the warmer seasons. The main reason for this is that when outdoor temperatures drop below the PCM melting point, the dynamic system may not function effectively on extremely cold days. As a result, the PCM layer remains positioned nearer to the interior, restricting its capacity to absorb heat from the outside.
The dynamic wall systems received an outstanding average System Usability Scale (SUS) score of 85, reflecting high levels of usability and user contentment. This result highlights how well dynamic walls fulfill user requirements and improve the home schooling experience for parents. Users perceived the system as intuitive and simple to use, indicating that the application of adaptive design principles has effectively tackled typical usability issues.
A notable aspect of the dynamic wall systems is their capacity to rearrange spaces rapidly and effectively. This adaptability is especially important in urban environments where making the most of restricted space is vital. Participants valued the option to tailor their home schooling parenting areas based on their evolving needs and desires, emphasizing how the system fosters spatial versatility and improves the user experience.
The research indicated that the dynamic wall systems not only performed effectively but also blended effortlessly with contemporary interior styles. Participants expressed appreciation for the streamlined design and the inclusion of practical features like storage and work areas. Achieving a balance between aesthetics and functionality is essential in modern residential design, where both visual appeal and practical use are greatly appreciated. The stylish, modern design and the incorporation of practical components such as storage and workspaces received positive feedback. Participants valued the system's capability to combine visual attractiveness with practical utility, making it a flexible option for different home schooling parenting situations.
Although the usability ratings were high, a few participants mentioned the necessity for more explicit instructions. This feedback implies that refining the onboarding experience might enhance the user's initial interaction. Offering detailed guides, tutorials, or even engaging help features could support new users in grasping and using the system more efficiently.
Several participants pointed out that some controls might be made more intuitive. This suggests that, while the system is largely user-friendly, there are particular elements of the user interface that could be improved. Streamlining controls and adopting more widely recognized symbols could further boost usability. Although the system was generally viewed as dependable, some users noted that they needed occasional technical assistance. Providing strong customer support and offering clear user manuals will be crucial for ensuring sustained high levels of user satisfaction in the future.
B. Results
The usability testing demonstrated that the dynamic wall systems are highly usable and satisfy user needs effectively. The high SUS score and positive qualitative feedback underscore the system's potential to enhance spatial flexibility and user satisfaction. However, the feedback also points to opportunities for improving user onboarding, refining the user interface, and ensuring reliable technical support. These insights will guide future design refinements, ensuring that the dynamic wall systems continue to meet and exceed user expectations. The usability testing of the dynamic wall systems yielded significant results, demonstrating the system's strengths and highlighting areas for enhancement.

Quantitative Results
Average Usability Score: The dynamic wall system achieved an average SUS score of 85, indicating high usability and user satisfaction.
Task Completion Rates: 95% of participants successfully completed the tasks assigned, with a noticeable decrease in completion time as users became more familiar with the system.
Ease of Use and Satisfaction Ratings: Participants rated the system's ease of adapt at 4.3 out of 5 and overall satisfaction at 4.5 out of 5, reflecting a generally positive experience.

Qualitative Results
Positive Feedback: Participants found the dynamic wall system intuitive and easy to operate, with many appreciating its user-friendly interface and straightforward controls.
The system's flexibility and adaptability were highly valued, particularly in optimizing home schooling parenting spaces in smaller apartments. The modern home schooling design and integration of functional elements such as storage and workspaces were well-received. Suggestions for Improvement: Clearer instructions and more intuitive controls were suggested as areas for enhancement. Some participants indicated a need for occasional technical support, highlighting the importance of robust customer service.

The effect of the key properties of the PCM Results
The properties of PCM play a pivotal role in shaping the thermal performance of walls equipped with a dynamic PCM layer. This section explores the influence of varying PCM melting temperatures and PCM layer thicknesses to optimize the wall's thermal behavior.
(a) Impact of different thicknesses of PCM
This section examined how different thicknesses of phase change materials (PCM) influence yearly heat loads, utilizing a range of thicknesses between 0.5 cm and 4 cm. To obtain the maximum annual heat gain (− 5.26 kW·h/m2) throughout

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the summer, the dynamic PCM layer on the building wall should be 2 cm thick, as shown in Fig. 15(a). Additionally, increasing the thickness from 0.5 cm to 2 cm enhances the indoor cooling delivered by a factor of 14.3. This is due to the fact that the PCM can significantly change at thicknesses below 2 cm; therefore, increasing the amount of PCM could enhance the latent heat capacity to absorb heat indoors. However, when the thickness surpasses 2 cm, natural cooling becomes inadequate to fully solidify the PCM, restricting its capacity to utilize latent heat effectively. Consequently, an increase in thickness leads to a rise in the average temperature of the PCM, diminishes the heat storage capacity, and ultimately results in less heat being released from the interior. Similar findings are noted in the literature [31]. Figure 15(b) illustrates the annual heat loss for various PCM layer thicknesses throughout the winter. It is evident that as the thickness of the PCM layer increases, heat loss diminishes. The most effective PCM layer thickness is 4 cm, which achieves the lowest heat loss (12.74 kW·h/m2) and a 13.52% decrease compared to a 0.5 cm PCM. This is due to the fact that, with this movement control strategy for the PCM layer, a thicker PCM can offer more sensible heat indoors and lessen yearly heat loss. As detailed in Section 2.3, the PCM layer shifts to the interior when the external surface temperature drops below the melting point. This action prevents the transport of latent heat from the PCM, allowing the transfer of sensible heat into the interior throughout the winter months. Table 6.1 displays the annual heat loads of the wall for different PCM layer thicknesses. The optimal PCM thicknesses are 2 cm for summer and 4 cm for winter, resulting in an annual heat gain of -5.26 kW·h/m2 and an annual heat loss of 12.74 kW·h/m2. The preferred thickness of PCM.

Table 6.1: Annual heat loads of different melting temperatures.

The thickness (cm)	Annual heat gain kW.h/m^2	Annual heat loss kW.h/m^2	Total annual heat kW.h/m^2
0.5	-0.34	15.60	15.26
1	-3.14	15.16	12.03
1.5	-4.93	14.61	9.69
2	-5.26	14.28	9.02
2.5	-4.39	13.72	9.33
3	-3.07	13.18	10.11
3.5	-0.56	12.97	12.41
4	0.54	12.74	13.28

(b)The key properties of the wall

(b.1) Impact of the thicknesses of the exterior and interior walls

The external and internal walls, illustrated in Fig. 1, play a vital role in managing heat exchange between the outdoor and indoor environments and the dynamic component. In this section, we assess the thermal performance of the dynamic system to determine the ideal wall thicknesses by varying the thickness of both the outer and interior walls. To comprehend their influence on thermal efficiency, we examined wall thicknesses from 1 cm to 15 cm (specifically 1 cm, 2 cm, 3 cm, 5 cm, 10 cm, and 15 cm). Figure 16 shows the annual heat gain of the dynamic wall during summer temperatures for different combinations of external and interior wall thicknesses. It is crucial to note that a negative heat gain value indicates the transfer of heat from the indoors to the outdoors. According to Fig. 16(a)-(d), where the thickness of the external wall is between 1 cm and 5 cm, we can see that each combination results in a negative annual heat gain. This discovery suggests that decreasing the outer wall thickness significantly improves the cooling efficiency of the building. The combination of an outer wall of 1 cm and an inner wall of 1 cm shows the most effective thermal performance and cooling effect (-10.69 kW·h/m2). This occurs because a thinner exterior wall reduces thermal resistance between the dynamic system and the outside environment, allowing for more efficient use of free cooling to solidify the PCM layer in colder months. Furthermore, a thinner inner wall enhances heat absorption from the interior, resulting in a more considerable reduction in annual heat gain during summer. Additionally, increasing the inner wall thickness leads to greater annual heat gain when the exterior wall thickness is less than 5 cm. However, Figures 16(e) and 16(f) illustrate that all annual heat gain values associated with different inner wall thicknesses are positive for exterior wall thicknesses of 10 and 15 cm.

This indicates that substantially thicker outer barriers negatively affect the thermal efficiency of this dynamic system. The rationale behind this is that larger external walls restrict heat transfer from the dynamic element to the outside environment, diminishing the necessity for free cooling and consequently limiting the PCM's heat storage capabilities. Conversely, when the thickness of the exterior wall exceeds 10 cm, an increase in the thickness of the interior wall leads to a decrease in the wall's annual heat gain. Figure 17 illustrates the varying trends in yearly heat gain during the summer with different exterior and interior wall thicknesses. When the thickness of the exterior wall is below 5 cm, the yearly heat gain usually rises as the thickness of the interior wall increases. However, when the exterior wall thickness is 10 and

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15 cm, the yearly heat gain decreases as the interior wall thickness increases.

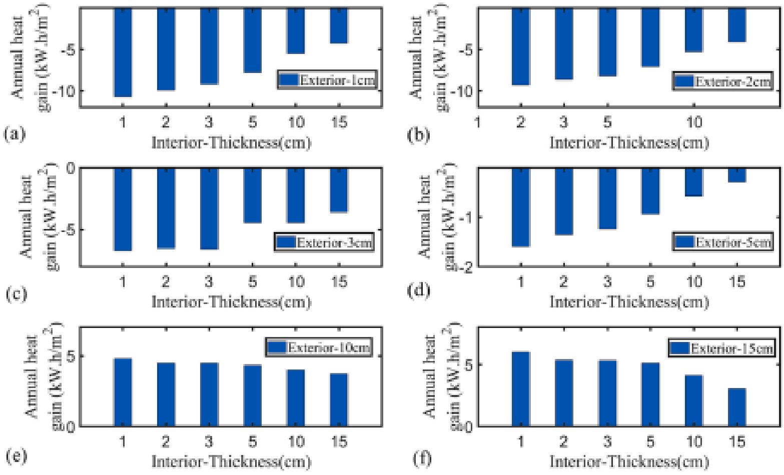

Fig. 16. Annual heat gains of different thicknesses of the exterior wall, (a) 1 cm, (b)2cm, (c)3cm, (d)5cm, (e)10 cm, (f)15 cm.

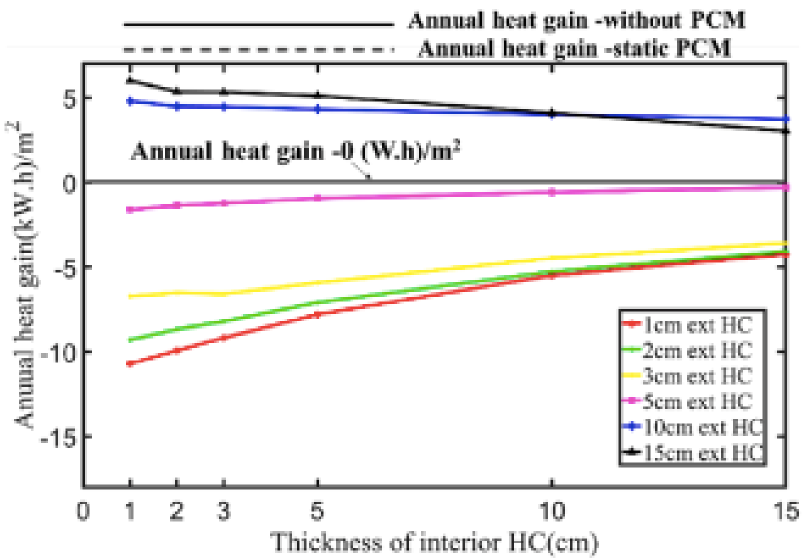

Fig. 17. The changing tendencies of the annual heat gains with different thicknesses of the wall.[51]

Table 6.3: Annual heat load of different wall thickness.

Thickness of wall: Exterior wall(cm)	Interior wall(cm)	Annual heat gain (kW.h/m^2)	Annual heat loss(kW.h/m2)	Annual heat load(kW.h/m^2)
1	1	-10.69	23.96	13.26
	2	-9.93	22.32	12.39
	3	-9.17	20.68	11.51
	5	-7.79	18.27	10.48
	10	-5.49	14.49	8.99
	15	-4.25	12.46	8.22
2	1	-9.29	22.98	13.68
	2	-8.67	21.34	12.67
	3	-8.20	19.97	11.77
	5	-7.09	17.72	10.63
	10	-5.26	14.28	9.02
	15	-4.07	12.36	8.29

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3	1	-6.72	22.01	15.29
	2	-6.51	20.50	13.99
	3	-6.58	19.29	12.70
	5	-5.26	17.12	11.20
	10	-4.07	14.02	9.56
	15	-7.09	11.85	8.26
4	1	-6.72	20.03	18.44
	2	-6.51	18.77	17.41
	3	-6.53	17.78	16.55
	5	-4.47	16.07	15.14
	10	-3.59	13.37	12.80
	15	-1.60	11.55	11.26
10	1	4.80	16.58	21.39
	2	4.49	15.09	20.46
	3	4.47	14.33	19.56
	5	4.33	12.44	18.65
	10	4.01	11.03	16.45
	15	3.74	14.23	14.76
15	1	6.00	13.78	20.23
	2	5.36	12.72	19.14
	3	5.34	11.28	18.73
	5	5.12	10.09	17.84
	10	4.11	12.45	15.39
	15	3.05	16.56	13.14

thickness. Specifically, when the thickness of the inner wall is increased from 1 cm to 5 cm, the annual heat gain increases by 27.12%, 23.71%, 11.24%, and 41.46% for external wall thicknesses of 1 cm, 2 cm, 3 cm, and 5 cm, respectively. On the other hand, when the inner wall thickness is raised from 10 cm to 15 cm, there is a reduction in annual heat gain by 22.71%, 22.63%, 19.65%, and 49.14%. For outer wall thicknesses of 10 cm and 15 cm, increasing the inner wall thickness from 1 cm to 15 cm results in decreases in annual heat gains of 22.12% and 49.13%, respectively. These patterns can be better understood by recognizing that when the outer wall thickness is less than 5 cm, boosting the inner wall thickness enhances the thermal resistance between the interior space and the PCM layer.

As a result, the dynamic system finds it challenging to effectively absorb indoor heat, leading to a rise in the annual heat gain of the wall. On the other hand, as the thickness of the outer wall increases, the overall thermal inertia of the wall also grows, while the effect of the dynamic system lessens. Once the outer wall thickness surpasses 10 cm, the effect of increased thermal inertia on the wall's thermal transfer becomes more pronounced than that of the dynamic PCM layer. Therefore, as the inner wall's thickness becomes greater, the yearly heat gain consistently decreases.

VII. CONCLUSION

The version of this template is V2. Most of the formatting instructions in this document have been compiled by Causal Productions from the IEEE LaTeX style files. Causal Productions offers both A4 templates and US Letter templates for LaTeX and Microsoft Word. The LaTeX templates depend on the official IEEEtran.cls and IEEEtran.bst files, whereas the Microsoft Word templates are self-contained. The investigation into dynamic interior walls utilizing Dynamic Wall Shape Memory Polymer Composite Phase Change Materials (DSMPCM) demonstrates significant enhancements in the thermal performance of building envelopes. Key insights from the research include:

• Improved Thermal Management: DSMPCM systems make effective use of latent heat for cooling storage, leading to consistently reduced inner heat flux when compared to traditional walls with static PCM layers or those without PCM.

• Boosted Energy Efficiency: The adaptive nature of DSMPCM facilitates thermal management that shifts in response to conditions, minimizing heat flux variations and delivering indoor cooling during summer months.

• Enhanced Performance Relative to Static Systems: In contrast to static PCM systems, DSMPCM provides superior regulation of heat transfer, achieving and sustaining negative heat flux values while more effectively minimizing temperature fluctuations.

The results highlight the capability of DSMPCM systems to enhance energy efficiency and indoor comfort in residential designs, suggesting a more adaptable and user-centered model in contemporary architecture [89]. This study introduced an innovative wall structure that incorporates an air layer, a PCM layer, and two exterior layers, leading to a dynamic,

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multi-layer wall system with the PCM layer being mobile within the wall. We conducted simulations using COMSOL Multiphysics to assess the thermal performance of the DSMPCM and examine how key parameters affect its efficiency. The principal conclusions from this study include the fact that the DSMPCM wall markedly lowers heat transfer through building envelopes when compared to static PCM walls or those lacking PCM altogether. This decrease is observed throughout the year, resulting in less annual heat retention and loss. This enhancement is accomplished by strategically placing the PCM layer within the wall to utilize passive cooling and heating techniques. The ideal melting temperature for the dynamic PCM in July is found to be 22 ◦C. Our results indicated that elevating the PCM melting temperature from 19 ◦C to 26 ◦C led to a reduction in yearly heat loss. For summer conditions, a PCM layer thickness of 2 cm is deemed suitable, while for winter, increasing the PCM layer thickness from 0.5 cm to 4 cm consistently decreased annual heat loss. Changing the thickness of both external and interior walls has a significant impact on the building's thermal efficiency. Thinner wall layers often increase thermal performance in the summer, but thicker wall layers improve thermal performance in the winter. It is worth noting that the thickness of the outer wall has a greater impact than the inside wall. Furthermore, a 4 cm air layer thickness gives the maximum thermal resistance, which improves the system's overall efficiency [90]. To enhance heat absorption indoors on hot summer days, the condition temperature for shifting the PCM layer should match the PCM's melting temperature. During the winter, however, the condition temperature should be adjusted lower than the melting temperature to allow the PCM layer to remain at the outside position for a longer period of time, lessening the influence of outdoor low temperatures on the structure.

While this study examined the thermal performance of the unique dynamic PCM layer technique and evaluated the impact of important parameters, the combined effects of these elements on optimal performance were not analyzed. In the future, it is recommended to use a multi-objective optimization strategy to select the most favorable.

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BIOGRAPHY

Raoul Jospin Rema is an entrepreneur and visionary leader with a solid background in architecture and design. He is the founder of Yevultov Holdings Limited, a dynamic marketing agency, and a co-founder of HGS Group, a green energy solutions company that focuses on ecologically friendly construction materials and cars. Raoul also works as a business developer for **Neza Technology Co., LTD**, a venture capital firm that specializes in innovation and technology. Raoul holds a degree in Architecture and Design and is an active researcher in industrial design, with a current concentration on interior design. His professional activities demonstrate a strong commitment to sustainability, creativity, and transformative solutions for emerging markets.