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Review Article Open Access

Modernize the Courtyard House

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Abstract

It is acknowledged that the courtyard house is one of the most important types of vernacular housing in the world, especially in the Arab countries. However, the use of courtyard house has not excluded on the vernacular architecture in the twentieth century, modern architects in their latest work tried to rediscover this type again. This paper discusses this rediscovering, and clarifies different ways of adapting vernacular concepts of courtyard houses to produce a modern one. Modernists combined the historical authenticity of this type with the requirements of modern life as well as with the modern methods of design and construction. Three famous ways of modernizing the courtyard house are clarified in this paper, in order to discover influences of vernacular concepts on the modern movement as well as tools of developing this type in the modern architecture. The paper concludes that the courtyard house as a type has passed several stages of modernization: simulation, integration, and transformation. In all these stages, the ability of the courtyard house to keep up with the times and achieve a remarkable success in modern architecture is observed. Therefore, it is possible to modernize the courtyard house in line with keeping qualities found in the vernacular architecture. As a result, this encourages architects around the word to keep discovering new ways of adapting this type to the contemporary needs.

Keywords: Courtyard house; Housing design; Modern architecture; Vernacular housing

Introduction

It is important to study the courtyard house as a type, and display its applicability in the contemporary and modern architecture. A successful architecture from our point of view is the one that considers the past and tries to develop it's suitability to the modern age. Architecture that ignores centuries of human interaction with the environment will not survive for a long time [1]. Many studies introduce vernacular concepts as a solution for contemporary problems. On one hand, the social benefits of the courtyard house characterized by the proximity of people from each other [2] and at the same time maintaining the privacy of individuals and groups [3]. On the other hand, there is a great deal of studies about the environmental benefits of using the courtyard in housing environment; the reason behind is the great assistance for thermal control and exploitation of natural lighting [4]. This type also achieves high density, which reduces the consumption of land and building materials [5], and helps to reduce the cost of operating the houses [6]. As a result, the courtyard house can be seen as a sustainable approach for contemporary and modern housing design.

Figure 1 shows the concept of vernacular courtyard house, based on a central patio that used for moving between different spaces of the house while remaining the main space for different family's activities during day and night [7]. The figure also shows the way of articulating the courtyard houses wall to wall to formulate a dense and coherent fabric.

The great benefits of using the courtyard house releases the question about the limited use of this type in the contemporary times. Although the courtyard house was a result of successful interaction between man and his environment in the Arab countries [8], the use of this type has been reduced often in these countries since the twentieth century[1]. Some academics may regard this reduction to the compatibility with modern requirement, and some may consider it just a part of the heritage. Thus, the rejecters of this type of housing may invoke modern requirements such as the modern family composition, the use of modern building materials, modern transportation methods, and others. Therefore, it is necessary to shed the light on the ability of the courtyard house to absorb such modern requirements while preserving mentioned environmental and social benefits.

Rediscovering

The architects of modernism already proved this ability in many projects of housing in the second half of the last century[2] [9]. Vernacular courtyard houses inspired the architects of Europe at that time to experience a dens and low-rise building type[3]. Modernists attempts to discover such new housing types as a try to find solutions to social and environmental problems created by modernity [10]. The search for these desired solutions greatly influenced by the type of the courtyard house that was prevalent in the vernacular Arab regions [11]. These experiences could encourage examining the use of the courtyard house after that in many projects in Europe seeking for sustainable housing environment.

At the beginning, the experiments focused on characterizing the fabric of courtyard houses with modern forms. Characterization followed then the rules of modern architecture, the most important of which were: Standardization of sizes following a selection of suitable pattern or a grid for articulating courtyard houses in a coherent fabric [12]. Streets and public squares were also created in the reference of the

[1]This can be considered a cradle of courtyard house through the ages.

[2]After neglecting the type of the courtyard in the first half of the 20th century by modern architecture and the blatant tendency towards high-rise residential blocks

[3]Unlike that of the 1940s and 1950s in residential buildings in which High rise residential block was the common type of housing in the post war architecture in Europe.

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Figure 1: To the left a schismatic plan for the vernacular courtyard house; to the right an aerial view of the vernacular fabric in Marrakech-Morocco.

same pattern, in addition the use of modern materials in construction such as concrete and precast concrete. Such experiments focused on speed in performance and the reduction of construction costs, in order to meet the needs of low-income householders. Besides, experiments tried to regulate the shape of streets and giving them the ability for passing cars. In this way, the result became a modern fabric of low-rise and dense typologies.

To achieve the objective of this paper, authenticity and modernization of designing courtyard houses in modern architecture will be the key of the following text. Such experiments of modernizing the courtyard house in the modern architecture will be discussed and clarified. These experiments ranged from the direct simulations of vernacular concepts to the integration of these concepts into modern concepts and thus the transformation of these concepts type to meet the contemporary needs. The following will discuss the efficiency of the vernacular concepts in responding to previous experiments and clarifying them through selected case studies.

Simulation

The term 'simulation' refers to the vernacular courtyard house, which is the procedure of designing similar houses with slight changes. Modernizing the design is limited to using simple modern tools: regular shape, and modern construction methods. However, the concepts of designing the house itself are not improved. The courtyard is still the central element of the house that is used for circulation between interior spaces as well as its use as a center of family's activities. The kitchen and the bath are separated from other rooms by the court.

The case of Casablanca is a good example of this simulation[4]. In this case, the goal is not to focus on modernizing the single unit and its spatial design, but rather to create strong relationships between units. Architects aimed to form a coherent fabric that simulates the vernacular fabric of the courtyard house in the Arab regions [13]. Simulations can also be observed in street design, which consists of gradients in the movement from the public to the private to the semi-private, with a focus on the fact that the streets are narrow, dense, and full of closed ends (Cul-de-sacs).

However, simulating the vernacular house in a modern way faced some challenges. The design of the modern home should be characterized by small size in order to suit the size of the contemporary nuclear family. Yet, the vernacular courtyard house often had a large size[5]. The large projection of the courtyard house helped to have the inner space in the center and therefore the size of this space was proportional to the height of the house[6]. As a solution, the "L shape" had been used in the design of the housing units, which encloses a space complementary to the shape of the rectangle; this space is the courtyard. The modern form of the house gave the designer a great flexibility to reduce building height to one floor, and reduce the size of the yard to range the size of a normal room. However, the modern design of the courtyard has the ability to preserve the environmental and social benefits of the courtyard (Figure 2).

Integration

The term 'integration' means the process of mixing the vernacular concepts with the modern concepts of designing the house and its context. In this case, many modern concepts are adapted in designing the house, such as separating functions by rooms, using interior corridors to decrease the role of the courtyard as a circulation element. Other modern concepts of articulating housing can be found such as horizontal or vertical rows. In addition, the use of the previous tools of modern architecture such as standardization and modern building materials still vital. However, vernacular concepts are maintained, especially the existence of the courtyard as a main source of organization as well as the main source of lighting and ventilation. The result of this integration could have a great potential to produce new housing typologies.

The case of "Malagueira housing" is a good example; the integration of vernacular concepts with modern concepts is remarkable. In this case, the use of frequent unit classified in rows is observed, but much attention is paid to designing the house to include many spaces- compared to the previous example- distributed on two floors. However, the house is still suitable for single family use that provides a private space for different activities.

In this example, a design of five-bedroom house around the

[4]The project of Casablanca is one of the first experiments carried out by the pioneers of modern architecture to revive the idea of the courtyard house. Because of that, it was considered as the city of tomorrow [14]. It started in Morocco then moved to Europe to take advantage of these experiences in providing social housing.

[5]Up to 800 square meters, the large size fits with the extended family size in the peasant time.

[6]As much as the height of the house increases the need for greater size of the interior space increased, which contrasts with the need for the reduction of housing units as much as possible.

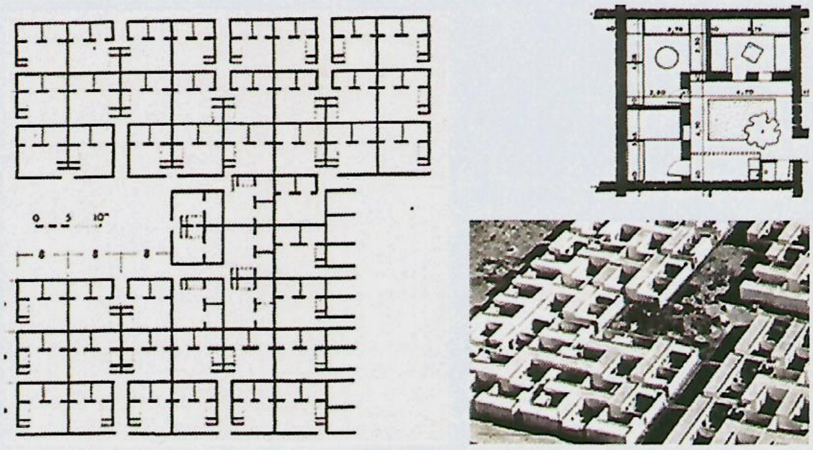

Figure 2: ATBAT-Afrique housing, in Casablanca- Morocco, By Candilis and Wood 1953. To the left the way of articulating the courtyard housing in a dense mat; upto the right-a plane of the housing unit shows "L shape" structures around the courtyard; to the right-down an aerial view of the project.

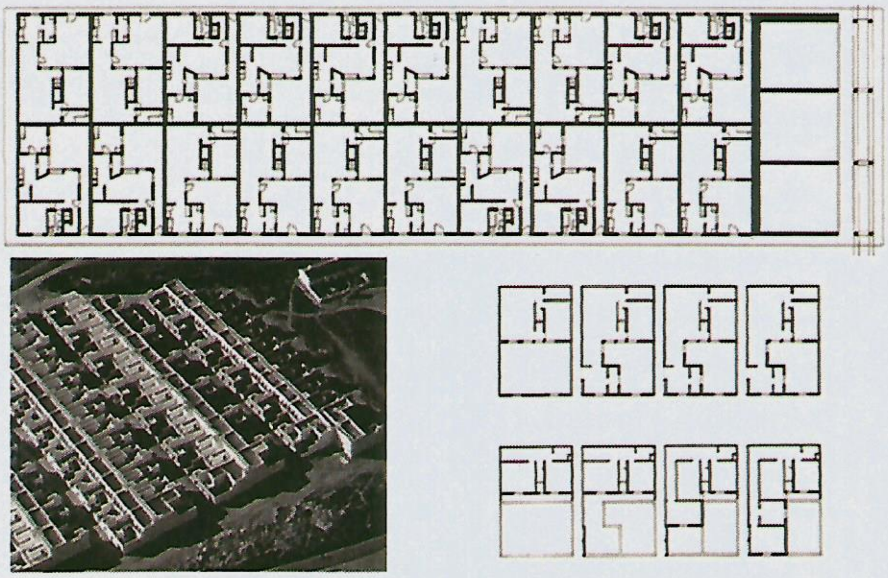

Figure 3: Malagueira Housing, in Évora City-Portugal, by Álvaro Siza. Up is a master plan which shows the way of articulating courtyard houses back to back in rows; to the left is an aerial view of the project; to the right different possible stages of growth for the house between the two floors.

courtyard is adopted. Such rooms can be built gradually according to the need of the family, and their financial capacity. The plan was developed by eliminating the role of courtyard for the circulation between rooms [14]. However, the courtyard is still a very important part of the house, because it provides a private and safe space for different family uses (Figure 3).

Transformation

The term Transformation is used here to describe a wider transition of the courtyard house that exceeds simulation and integration. It is the convert of the courtyard house to. an urban type of settlement[7]. To innovate a new experience of modern housing that meets modern needs. In this way the courtyard house is transferred into a dwelling that belongs to a wider context. Thus, the courtyards become shared spaces. However, courtyards still have the ability to preserve their environmental and social characteristics. Besides, courtyards become a part that has stronger relations with the whole settlement, which encourages cooperation between different families.

The case of Menorca housing is a good example of transformation. The development of the courtyard house was through using layers of houses that attached to each other using "u shape" houses. Articulation of unites using layers required the existence of interior corridors or street[8] that facilitate reaching all houses. An aerial view to this housing will clarify the idea of strong relation between units to formulate one building as a mat[9]. The inner courtyard in this case becomes common among more than one house. Using the courtyard with this special

[7]Comparing with the previous examples, in which shared spaces are limited. Such spaces are an important element of planning urban neighborhoods today.

[8]Le courposier was the first who named the interior corridor a "street" in his famous housing project "Unit d' Habitation" in Marseille-France.

[9]This type is influenced by Mat Building which is an organization method of urbanism based on low-rise and dense typologies [8].

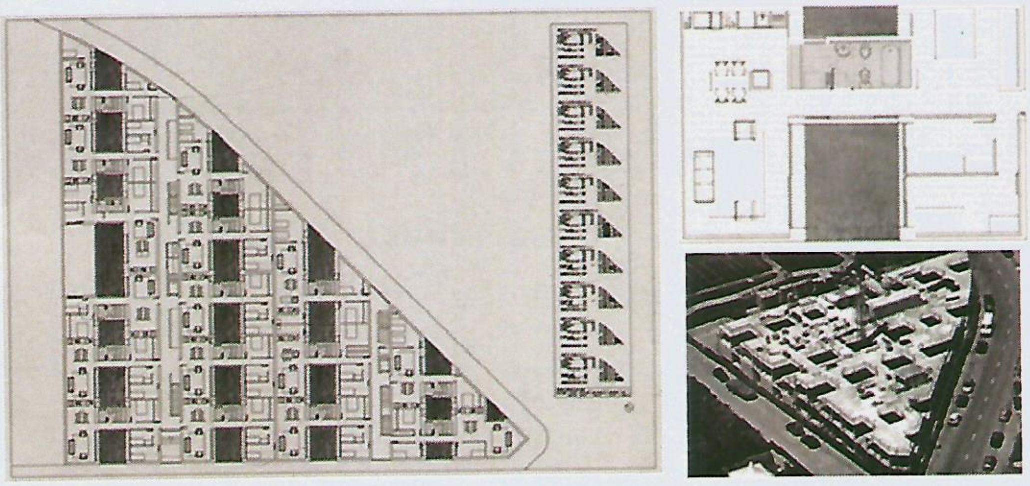

Figure 4: Social housing of Es Mercadal, in Menorca-Spain, By Jaime J. Ferrer Forés. To the left the way of articulating housing units using layers of courtyards and streets, to the right-up the use of "u-shape" housing units that views duple courtyards, to the right-down an aerial view of the housing project.

composition was to provide lighting and ventilation to all rooms and create a clean and quiet atmosphere away from the hustle and bustle of the city [15]. The house has also limited overlooking on its backyard patio [16,17]. This development of using the courtyard can be seen as a need for modern society for sharing spaces, in which houses share the entrances and services with other houses (Figure 4).

Conclusion

The preview of the previous case studies has revealed that the traditional courtyard house was modernized with the respect for its authentic roots. This modernization has passed three main stages. These stages which ranged from simple and direct simulation of the courtyard house, to the fusion of Western concepts with the traditional concepts, reaching to devising new ways of dealing with the inner courtyard. This modernization sustains the idea that courtyard house has the great potential and flexibility to deal with different demands of the modern age of architecture. Functional wise, there are three main uses of the courtyard that can be differed according to the need. The first is using the courtyard as a circulation element as it could have a fundamental or secondary role for residents' movement between interior spaces. The second is using the courtyard as a private space for the residents, which could have a fundamental or secondary role for their social activities. The third is using the courtyard for providing lighting and ventilation, which always has a fundamental role for healthy environment. Therefore, the courtyard has always been able to maintain its status as the most important element of designing the courtyard house. Finally, the previous cases may help, on one hand, in developing some ideas for modernizing the courtyard house, which shade lights for the possibility of adapting vernacular concepts in the modern design. On the other hand, it is our belief that the door is still open for more innovations of designing courtyard houses in the future. This kind of innovations is an important approach towards housing that combines authenticity and modernity both in one design.

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Perception of Open Spaces Integration in Maternity Hospital Designs in Kaduna, Kaduna State, Nigeria

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Abstract

The awareness of the positive effects of open spaces whether indoor or outdoor on patients' healing process has long been identified in hospital architecture and the integration of open spaces for the purpose of therapy has begun to be applied. This research aims to provide a new holistic approach to maternity hospital design that involves relieving the fears and disorientation of patients (through the integration of open spaces in maternity hospitals for such therapeutic functions) that may hinder medical treatment. Qualitative research method was applied for this research, making use of case study approach and application of observation schedule. Results of this research show that there is total disregard of the use of open spaces in hospital design. The research recommended that there should be consideration towards the integration of open spaces into future maternity hospital design.

Keywords: Maternity; Hospital; Courtyards; Open spaces; Therapeutic

Introduction

The cognizance of the positive effects of open spaces whether indoor or outdoor on patients' healing process has long been identified in hospital architecture [1]. It has become very vital to not only provide open spaces that have therapeutic functions for patients, but also to create a connection between the interior of health care centres and exterior landscaping features [2]. As a structure that is committed to the wellbeing of man, a health facility should have a serene environment for healing, which helps patients and their relatives to be restored to perfect state of health. There is a growing interest in the architecture of hospitals for a 'patient-centred' design of hospitals by the integration of physical environment (open spaces) in form of courtyards, front porches, and vegetative land cover to improve patient perception and health expectations within this environment [3]. Therapeutic open spaces function to provide physical settings and organizational culture that support patients and families through the stresses imposed by illness, hospitalization, medical visits, the process of healing sometimes, bereavement and in this case health complications associated with maternity. Hospitals have been criticized for their poor spatial qualities and disregard towards the patient, who is supposed to be in the genesis of its core [4]. According to Dejana Neducin et al. as patient's perception while staying in a hospital is frequently distorted, limited and influenced by various external factors, the patient is in constant need of a greater support than in everyday circumstances, through the provision of open spaces for therapeutic reasons [5].

Literature Review

Maternity hospitals

Maternity hospitals, also called lying-in-hospitals are hospitals dedicated to women during their time of pregnancy, during and after child-birth. Maternity hospitals provide care to women and their new born infants either in a maternity department located within a general hospital or existing as a stand-alone hospital (Health Information and Quality Authority 2016). Clinical training in midwifery and obstetrics also take place in maternity hospitals. Maternity hospitals were founded in the nineteenth century as urban-based charity shelters to serve the unfortunate, homeless, and working class poor population that had a high infant mortality rate. A tactic to solve this problem was to improve maternity care for this group [6]. The maternity hospitals in our day have been regarded as vital part of the urban fabric that is open to the community; this is the same as other public buildings. This new approach in planning and designing of both indoors and outdoor spaces has achieved a shift in hospital's public image; where patients no longer feel isolated or secluded from rest of society.

Open spaces

The term 'open space' refers to green space consisting of any vegetated land, structure, water, path or geological feature within buildings and on the edges of settlements, in civic space consisting of squares, market places and other paved or hard landscaped areas with a civic function [7]. Open spaces can also be defined as land which are openly accessible and have been designated for leisure, play, recreation or sport. The uses of open spaces can either be for passive or active reasons. Active open spaces are usually for sport, exercise or active play; while passive open spaces are used for seating and relaxing. The application of passive spaces is more effective in this instance. Open spaces found within buildings and structures have significant impact on the occupants and the state of the structure as well. The presence of natural spaces nearby improves well-being and access to or views of the natural environment to improve mental functioning and help in recovery from surgery and sickness [8]. According to Peter and Daniel, these open spaces which are often characterized by the presence of high green coverage in forms of grass, shrubs and trees have therapeutic, ecological and environmental importance [9]. Through their importance, open spaces can help people find within areas they are located in adjusting to healthy lifestyles, hence the encouragement to integrate this building features into healthcare facilities. In recent times, there has been an increase in attention directed towards research

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concerning the evaluation of open spaces (including green areas and green spaces) and their components as well as their effect on the environment. According to Ulrich et al. open spaces are necessary components of structures, but poor design of an open space can lead to misuse and unused areas, undesirable behavior, strain on management, and other difficulties [10]. The presence of open spaces in structures should be;

1. Reasonable to manage,
2. Flexible in use and therefore adaptable,
3. Able to foster a sense of ownership so that residents become involved in maintaining the space and
4. A positive impact on the surrounding natural resources.

Open spaces in hospitals

Dejana Nedučin et al. observed that during the review of the development of hospitals through history, the acknowledgement of the positive effect of open spaces, natural environment on patients' restorative process has been present in hospital architecture [5]. Proof of strategic therapeutic/healing gardens can be traced to the European primitive monastic hospitals, where patients' cells enclosed around and had an uninterrupted access to colonnaded courtyards.

Criteria for the integration of open spaces within hospital areas

Accessibility: It is essential because people, patients, staff and users of hospital space need to be aware that the open spaces actually exist, and that they are easily accessible through entrances and paths and useable.

Visibility: The more open spaces are visible and people are aware of it, the more the activity areas and paths around and within it will be preferred. Patients' rooms should have views of the open spaces so that they can enjoy it even if they are unable to visit it.

Physiological comfort: As hospital patients are often sensitive to temperature, options such as sunny and shady areas should be provided, as well as seating that are shielded from breeze by plants or structures.

Quietness: Open spaces designed for therapeutic purposes should be quiet and removed from sources of noise or sounds inside the hospital.

Hospitals today have come to be regarded as vital parts of the urban context that are accessible to the community; this is similar to other public buildings. This fresh method in the planning and design of both interior and exterior spaces brought about a change in hospital's public image [5]. The open spaces to be integrated into the hospital environment should be perceptible from the wards of patients, interior interactive spaces and passageways, for both safety and medical purposes. Visibility out and through also provide ease as it is psychologically therapeutic, because it lessens the sense of seclusion and claustrophobia by providing an unbroken interaction with the outside world. It might also pique patient's interest to the surrounding environment, which would ultimately lead to either instantaneous use or a resolution to visit it later [11].

Benefits of presence of open spaces

Kant and Kumar [11] observed two benefits of presence of open spaces in the hospital to include:

- Ecological Benefits: Due to solar radiation, air temperature, wind speed and relative humidity varying considerably, as a result of built environment in cities, the urban heat island effect is caused by the large areas of heat absorbing surfaces; this can increase developed area temperatures of 5 degree centigrade. Therefore, a provision of open spaces consisting of vegetation and green cover within built environments can help to alleviate the situation. Climate and temperature regulation can be introduced within presence of natural environment infused in built up areas.
- Energy Saving: The introduction of natural environment into structures to reduce the energy costs of cooling buildings has been progressively recognized as a cost effective reasons for increasing green space and tree planting in built-up environments. Plants improve air circulation, provide shade and they evaporate-transpire.

Research Methodology

Observation method of research was employed. Observation method of research involves directly observing and studying a sample of a population. The assessment was conducted in Kaduna, Kaduna state, Nigeria. Ten hospitals six of which are private, two governments and other two of Catholic administration were selected deliberately by purposive sampling of non-probability sampling method. The selection of these hospitals was based on the existence of maternity departments in their structure amongst other hospitals lacking such. The population was divided into three local government areas which comprise of Kaduna North, Kaduna South and Chikun. Maternity hospitals were selected based on the geographical areas which make up Kaduna city using area random technique as indicated in Table 1. Data analysis took the form of simple descriptive statistics and content analysis represented in the form of percentages. Data collated was computed manually and tabulated in Microsoft Excel Spread Sheet Programme.

Findings and Discussion of Results

The results in Table 2 show that to a fair extent there is no total disregard of the provision of open spaces within hospital environments as event in plates I-V (Figures 1-5). It however shows that 30% of the hospitals analysed had no integration of open spaces within or around their structure. While, 70% of the health facilities observed as cases studies made provision for open spaces within their environment.

Table 3 shows that 80% and 50% of the hospitals studied interpret open spaces as being in the forms of front porches and courtyards. These are the most common forms of open spaces seen during the course of this research. While 60% had these open spaces in form of vegetative land cover and 30% as entry gardens and 10% as roof gardens. Walk-in gardens were however 20%.

S/No.	Name of hospital	Local Government Area
1	St. Gerard's Catholic Hospital, Kaduna	Kaduna South
2	Jowako Specialist Hospital, Kaduna	Kaduna North
3	Gwamna Awon General Hospital, Kaduna	Kaduna South
4	Harmony Hospital, Kaduna	Kaduna South
5	Sabo General Hospital, Kaduna	Chikun
6	Betheseda Clinic and Medical Centre, Kaduna	Kaduna South
7	Barau Diko Hospital, Kaduna	Kaduna North
8	Giltooe Aris Specialist Hospital, Kaduna	Kaduna South
9	Nasara Specialist Hospital, Kaduna	Kaduna North
10	Chasel Hospital, Kaduna	Kaduna North

Table 1: Name of hospitals sampled.

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S/No.	Name of Event centre	Available	Unavailable
1	St. Gerard's Catholic Hospital	✓	
2	Jowako Specialist Hospital		✓
3	Gwamna Awon General Hospital	✓	
4	Harmony Hospital		✓
5	Sabo General Hospital	✓	
6	Betheseda Clinic and Medical Centre		✓
7	Barau Diko Hospital	✓	
8	Giltooe Aris Specialist Hospital	✓	
9	Nasara Specialist Hospital	✓	
10	Chasel Hospital	✓	
	Total	70%	30%
	Percentage		

Table 2: Assessment of the provision of open spaces in the hospital environment.

Figure 1: Plate I-Courtyard in maternity unit in St. Gerard's Catholic Hospital.

Figure 2: Plate II-Open courtyard in St. Gerard's Catholic Hospital.

Figure 3: Plate III-Gwamna Awon general hospital Nasarawa road, Kaduna administrative block.

Figure 4: Plate IV-Gwamna Awon General Hospital Nasarawa road, Kaduna: Open space plaza within built-up environment.

Figure 5: Plate V-Walkway encircled around an open courtyard in Sabo General Hospital, Kaduna.

Table 4 shows that 80% of the hospitals have their open spaces at the entrance of their buildings and 50% are centrally located in forms of courtyards, while 50% provided open spaces in between built-up areas in their environments, 10% on the roofs and 40% around the structure.

Table 5 shows that 60% of the hospitals studied have a visual connection between the indoor hospital rooms or wards and the open spaces within the hospital environment. While 40% do not have any visual connection between the indoor hospital rooms or wards and the open spaces.

After studying open spaces in maternity hospitals in the study area, figure 6 showcases a design that has fully incorporated the importance

S/n	Name of Hospital	Vegetative land cover	Land scaped setbacks	Front porches	Entry gardens	Courtyards	Plazas	Roof gardens	Healing gardens	Walk-in gardens
1	St. Gerard's Catholic Hospital	✓		✓		✓				
2	Jowako Specialist Hospital					✓				
3	Gwamna Awon General Hospital	✓		✓	✓	✓		✓		
4	Harmony Hospital			✓						
5	Sabo General Hospital	✓	✓	✓		✓				
6	Betheseda Clinic and Medical Centre									
7	Barau Diko Hospital	✓	✓	✓	✓	✓				✓
8	Giltooe Aris Specialist Hospital	✓	✓	✓	✓					✓
9	Nasara Specialist Hospital			✓						
10	Chasel Hospital	✓	✓	✓			✓			
	TOTAL	6	4	8	3	5	1	1	0	2
	Percentage	60%	40%	80%	30%	50%	10%	10%	0%	20%

Table 3: Showing the types of open spaces available within or around the hospital.

S/N	Hospitals	At The Entrance	Centrally Located	In Between Structures	Outdoor And Around The Structure	On The Roof
1	St. Gerard's Catholic Hospital	✓	✓		✓	
2	Jowako Specialist Hospital		✓			
3	Gwamna Awon General Hospital	✓	✓	✓	✓	✓
4	Harmony Hospital	✓				
5	Sabo General Hospital	✓	✓	✓		
6	Betheseda Clinic and Medical Centre					
7	Barau Diko Hospital	✓	✓	✓	✓	
8	Giltooe Aris Specialist Hospital	✓	✓	✓	✓	
9	Nasara Specialist Hospital	✓				
10	Chasel Hospital	✓		✓	✓	
	Total	8	5	5	4	1
	Percentage	80%	50%	50%	40%	10%

Table 4: Location of open spaces in the hospital environment.

S/N	Hospitals	YES	NO
1	St. Gerard's Catholic Hospital	✓	
2	Jowako Specialist Hospital	✓	
3	Gwamna Awon General Hospital		✓
4	Harmony Hospital		✓
5	Sabo General Hospital	✓	
6	Betheseda Clinic and Medical Centre		✓
7	Barau Diko Hospital	✓	
8	Giltooe Aris Specialist Hospital	✓	
9	Nasara Specialist Hospital		✓
10	Chasel Hospital	✓	
	Total	6	4
	Percentage	60%	40%

Table 5: Assessment of visual connection between indoor hospital rooms and the open spaces as natural environment.

Figure 6: Integration of open spaces within the maternity hospital design as conceived by authors.

of open spaces for therapeutic function into the hospital design.

Conclusion

The study has revealed that the integration of open spaces into maternity hospital design has been neglected and considered irrelevant and unconnected to the psychology of the users of hospital space. It was observed that only 70% of maternity hospitals have no open spaces within their hospital environment. From oral interviews conducted with hospital staff and patients, it is alarming that users of hospital spaces see no need of open spaces within the hospital environment. The survey conducted however, shows optimism towards the vitality of the integration of open spaces into the hospital environment. The design of healthcare facilities is incomplete without the integration or application of open spaces for therapeutic function and psychological balance of the patients, staff and visitors. The lack of open spaces has an effect on the patients' journey to wholeness.

Recommendation

Future designs of hospital should be encouraged to make provision of open spaces within and around the hospital environment. Consideration as regards to the integration of open spaces within maternity hospital design should be learnt thereby creating suitable hospital environments where patients can be nursed back to wholeness both physically and psychologically.

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Adaptive Comfort Model Incorporating Temperature Gradient for a UK Residential Building

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Abstract

Thermal comfort field experiments were conducted to acquire thermal comfort data of 119 participants in a test house representative of a typical UK house. This paper compares the performance of popular PMV-based thermal comfort index vs neutral temperature based on Actual Mean Vote. The aim of this research was to incorporate vertical thermal gradient, which is usually a neglected yet highly influential parameter in a residential setting and propose a new adaptive thermal comfort model. The new adaptive model (LPMV) has been developed using a polynomial curve fit method. This method was chosen as it has the capability to correlate indoor environmental parameters with AMV and incorporated them in the generated mathematical model. The model requires temperature gradient and SET* only to determine neutral temperatures which makes it the first of its kind. The LMPV model was rigorously tested against thermal comfort data compiled in this study and against independent/unbiased data (the ASHRAE RP-884 database). LPMV showed up to 0.7°C improvement in predicting neutral temperature of occupants compared to the famous Fanger's PMV model. This can result in better prediction of a suitable heating setpoint temperature which has great implications on annual energy demand.

Keywords: Thermal comfort; Building physic; Temperature gradient; Fanger; AMV; PMV

Abbreviations: AMV: Actual Mean Vote; PMV: Predicted Mean Vote; LPMV: Loughborough PMV model; SET: Standard Effective Temperature

Nomenclature

ta: Air Temperature;

td: Dew-Point Temperature;

T0.6: Air Temperature at 0.6 m from the floor;

TG: Temperature Gradient i.e. temperature difference between 0.1 m and 1.1 m above the floor.

Introduction

The thermal comfort sensation of occupants in an indoor environment is dependent on the environmental conditions (air temperature, mean radiant temperature, operative temperature, air speed, absolute humidity) as well as their metabolic rate and clothing insulation. Fanger's comfort model known as Predicted Mean Vote (PMV) is typically used by researchers and practitioners in predicting occupant's thermal comfort. Fanger's PMV model assumed that thermal sensation is a function of the thermal load on the body and highlighted the associations using a mathematical model. This model was based on a survey of thermal sensation surveys collected from participants in a climate chamber. However, thermal comfort tests conducted in countries around the world show a variation in the accuracy of the PMV model in predicting occupant thermal comfort for both test chamber and field studies [1-4]. It has been advised that thermal comfort models need to be researched that are specifically applicable to a certain geographical location and climate. This encourages the investigation of a modified PMV model that is more accurate in predicting thermal comfort of European participants in a European winter climate.

After Fanger's PMV model, Gonzalez and Gagge proposed a two-node model that was suitable for a specific range of indoor air humidity and velocity known as Standard Effective Temperature (SET*) which is a subset of new Effective Temperature (ET*) under standardised condition in a sedentary activity [5]. ET* is defined as the dry bulb temperature (DTB) of uniform enclosure with 50% relative humidity at sea level [5]. After the addition of PMV into the ASHRAE and ISO 7730 standards in the early 1980s, Gagge et al. [1] improved the PMV model by incorporating ET* and SET* (Standard Effective Temperature) into the PMV formula and is known as PMV* [1]. Most of these studies were conducted in an environment chamber with seated participants doing sedentary activities with an assumed metabolic rate of 1.0 met.

Although Fanger's model was accepted as an international standard, the limitation of the application of the PMV model for practical non-air conditioning building has resulted in the development of different PMV variations. For example, for hot and humid climate ePMV was developed by Fanger and Toftum [2], aPMV developed by Yao et al. using black box modelling for Chinese participants and PMVn [3,6]. As these models were developed for different climates and cultures their suitability for UK residential buildings needs further investigation.

Humphreys and Nicol argued that the PMV model's success was due to the model being applied in air-conditioned buildings with narrow ranges of operative temperature [7]. They then developed a new thermal comfort model, based on the multiple regression analysis of the ASHRAE RRP-884 dataset with more dynamic ranges of indoor temperature. Zhang et al. conducted a human local discomfort study in a stratified environment by using a controlled environmental chamber with 109 participants which later developed the CBE comfort model [8].

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Yao et al. explored adaptive comfort with 3D curve fit method on PMV data [3]. Gao et al. developed eTSV and modified SET* model based on his dataset by using aPMV and ePMV methods [9]. This research distinguished the methods by air speeds of less than and more than 0.2 m/s. Gao et al. also found that the modified SET* had better accuracy in predicting the reported thermal sensation (TSV) compared to the modified PMV [9].

The performance of each of these models needs to be verified in predicting thermal comfort with the help of distinct databases. Thus, in this study the suitability of PMV-based models such as Fanger's PMV, Gagge Pierce two-node: SET* and new effective temperature ET* models were evaluated in a test house. Little research has been conducted in residential buildings with a large set of participants thus the aim is to use a large number of participants as test subjects. Additionally, as residential buildings with smaller volumes and radiator heating are more prone to sharp gradients in vertical air temperatures (temperature gradients). This is because of smaller volumes with 0.87 ACH may contribute to uneven air temperature during winter as a lower air change rate will reduce vertical air stratification [10].

In this paper, a new comfort model has been developed that incorporates temperature gradient of the space in predicting suitable temperatures for occupants. This was possible using the polynomial plot method [6]. In this method a 3D curve fit is plotted between three influential parameters to define the neutral temperature of the participants. This is different to linear fits that are plotted between two influential parameters. This method was chosen as it has the capability to correlate a second indoor environmental parameter with AMV [11].

Methodology

The test house

Thermal comfort tests were conducted from October to November of 2015 and November to December of 2016 in a two-storey detached test house with exposed mass located in the Midlands (Figure 1). The test house located in the Holywell Park of the Loughborough University campus is a North-West facing, two storey residential detached building with a pitched roof. The exterior of the test house is exposed brick work and was built in the 1998. It consists of 2 bedrooms, 1 kitchen, 1 living room, 1 toilet and 1 bathroom. The test house has a heat loss coefficient of 136 W/K and an infiltration rate of 0.87 ach measured in 3 consecutive seasons by Jack R. The infiltration rate was measured using a blow door test and is relatively high compared to an average of 0.4 each for a UK home. The house is classified as medium air tightness and is moderately insulated according to BSI-13790 [12]. All the comfort surveys and tests were carried out in the living room the dimensions of which are presented in Table 1.

Figure 1: Exterior isometric view of the test house.

Experimental procedure

A total of 119 students (both male and female) took part in the thermal comfort experiments. On average four subjects were present at each thermal comfort session. Participants from outside the house were then introduced into the kitchen area where they were explained the procedure of the experiments and asked to sign a consent form. The 30 min buffer in the kitchen was also created so that the participants became thermal neutral with the environment, meaning external weather affects became minimal. They were then taken to the living room where they were asked to take a seat on the sofas and carry out work such as reading or watching TV/tablet. The four subjects were allowed for any adaptive opportunities such as changing their clothing levels, opening a window or tempering with the heating system throughout the duration of the test sessions. The participants were asked to answer questionnaires at 0, 15, 30, 45 .... 120 minutes mark. For the same 15 minutes intervals readings were taken from the sensors and PMV was calculated. A total of 54 sessions of thermal comfort survey with different subjects were conducted and 1837 datasets were collected.

Sensor measurements consisted of 4 environmental indoor parameters (air temperature, mean radiant temperature, air velocity and relative humidity). These were measured by the thermal comfort kit (Figure 2a and 2b) with the detail specifications in Table 2. The operative temperature was measured via sensor whilst Tmrt was calculated using eqn. (1). The thermal comfort kit was placed in front of participants with a distance greater than 30 cm away from the subjects and at a height of 60 cm from the floor in the living room [13]. A data logger was used to measure the outdoor air temperature together with the air temperature stratification inside the room at heights of 0.1 m, 0.6 m, 1.1 m and 1.7 m from the floor. The participants were observed for their clothing levels and the activities they were conducting. These were then reference with CIBSE guide A to calculate an average clo value with the sofa resistivity of 0.76 clo with a tolerance of ± 0.04 and the sedentary metabolic rate of 1.0 met which is equivalent to 58.2 W/m².

$$Tmrt=(Top \times 2) - Ta \quad (1)$$

The survey measurements were based on the 7-point Bedford

Description	Area
Floor to ceiling height	2.35 m
Floor area	16.66 m²
Door area	1.68 m²
Windows area	4.49 m²

Table 1: Dimensions of the living room.

Figure 2: (a) Typical setup of participants filling in surveys (b) Thermal comfort kit for the indoor environment surveys.

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comfort scale and ASHRAE Standard 55 questionnaire on thermal sensation [14]. The participants were asked to report their thermal sensation (TSV/AMV) between -3 to 3 every 15 minutes. This may seem short time duration for the human body to adapt but skin sensation does adapt quickly. Another reason this time duration was chosen is because it is what past researchers have also utilised [15].

Performance Analysis of Current PMV Based Models

Before a new comfort model is generated for the current experimental data it was important to see which of the currently established comfort models perform the best in predicting thermal comfort of the participants. To conduct the performance analysis of the various comfort models a datum parameter was selected. For this study it was the neutral temperature (Tn) which is the temperature at which participants would feel the most comfortable with their thermal environment. Tn is calculated using the linear regression method on the AMV data points versus operative temperature (Top). The following PMV based models were chosen as the candidates:

ePMV=e × PMV (Fanger and Toftum) [2]

aPMV=PMV/(1+λ * PMV) (Yao et al.) [3]

PMVnew=0.8(PMV – Dpmv – vote) (Nicol and Humphreys) [7]

PMVn=–5.151+0.202Ta+0.553Vp (Orosa) [7]

TSVse=ePTS (Gao et al.) [9]

TSVsa=PTS/(1+λPTS) (Gao et al.) [9]

PMVashrae=–6.802+0.243Ta+0.278Vp (ASHRAE) [6]

PMVSET* =(0.028+0.303*e*–0.036*M*) × (H – Lset) (Gagge) [1]

ePMVgao=ep × PMV (Gao et al.) [9]

Please note: H is the internal heat production rate per unit area (W/m²). L represents all modes of energy loss from body (W/m²) in PMV. SET* will replace Top in PMV to become PMVSET*.

Also, $$ep = \frac{\sum_{i=1}^{n} TSVi \times PMV}{\sum_{i=1}^{n} (PMVi)^2}$$

The neutral temperature based on the AMV of all the occupants was determined using linear regression to be 23.4°C. This is higher than the recommended temperature range of 22-23°C by CIBSE for living rooms in a residential property [16]. It was interesting to understand how the different comfort models stated previously perform in predicting this neutral temperature. Fanger's famous PMV model predicted a neutral temperature of 24.2°C which results in a standard deviation (SD) of 0.8°C which is illustrated by red bars in Figure 3. In the same figure,

Instruments	Description	Range	Accuracy
Lumisense INNOVA 1221 Thermal comfort controller	Thermal comfort controller	N/A	±0.1°C
Operative temperature Model number: MM0060	Read indoor operative temperature	5-40°C	±0.3°C
Air temperature Model number: MM0034	Read indoor air temperature	5-40°C	±0.2°C
Relative Humidity Model number: MM0037	Read relative humidity, Dew bulb temperature	-20 to 50°C with Operating temperature: 5-40°C	ta-td < 10 K: ±0.5 K or ±0.05 kPa 10 K < ta-td <25 K: ±1.0 K or ±0.1 kPa
Air speed Model number: MM0038	Air velocity sensor	0 to 10 m/s	±0.05 m/s
Air Temperature Thermistor NTC U Type	Air temperature sensor for temperature gradients	-50 to 70°C	Accuracy of ±0.2°C
Onset HOBO U8-001-08	Air temperature sensor	-20° to 70°C	Accuracy of ±0.47°C

Table 2: Dimensions of the living room.

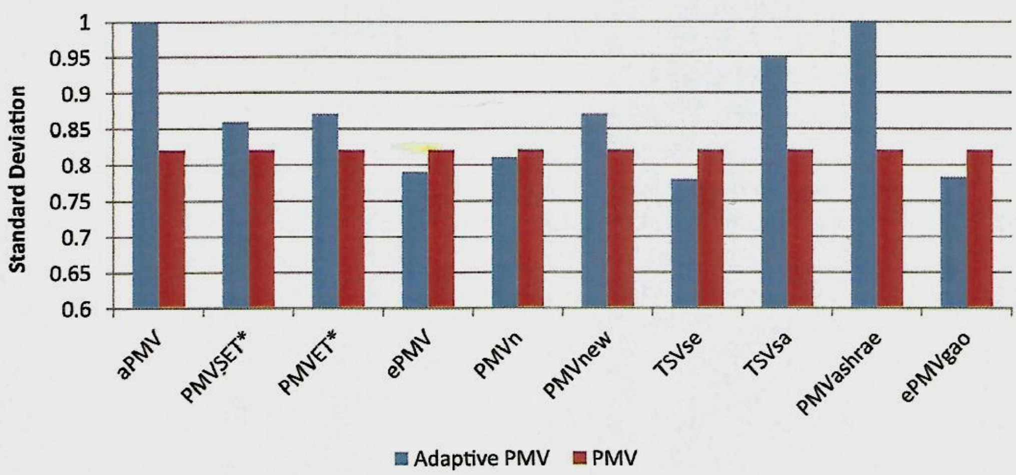

Figure 3: Standard deviation of different adaptive comfort models in predicting neutral temperature based on AMV.

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SD from utilising other adaptive models is illustrated using blue bars. It can be observed that TSVse and ePMVgao perform the best with an SD of 0.78°C and followed closely by ePMV with a SD of 0.79°C [17-19].

Incorporating Temperature Gradient

Temperature gradient (TG) in these experiments refers to the air temperature gradient between two points i.e. 0.1 m and 1.1 m above the floor. In this study, a temperature gradient of up to 7.3°C was measured. The average AMV during the study elucidated that participants accepted higher TG with ± 0.5 votes. How do you know if it was acceptable??? It was accepted due to based on Pearson's statistical correlation and significance carried out on the experimental data is was found that TG shows a strong correlation with AMV thus it was decided to incorporate the parameter into the comfort model using the curve fit approach used by Orosa and Oliveira and investigate its performance [11]. The curve fit approach consisted of plotting a 3D curve fit between three influential parameters to better predict occupant comfort (Figures 4-8). This method was conducted for numerous combinations of three influential parameters. Five of the best performing models are the following:

LPMV1=−0.294 − 0.02402 × TSVsa+0.13 × *TG*; TSVsa=(PTS/(1+λPTS)),

where, the adaptive coefficient λ was obtained based on the equation used by Yao and found to be 0.235. The PTS was equal to 0.1185 × SET − 2.7775 using Gao, et al. method [9].

LPMV2=−0.2864+0.08308 × e(PMV) +0.1308 × *TG*; e=0.8

$$LPMV3=-2.312+(0.4685\times T_G)+0.09622\times SET^*-(0.002211\times T_G^2)-0.02085\times(T_G\times SET^*)+0.0835\times T_G$$

$$LPMV4=-13.79+(0.8493\times T_{op})-(0.2678\times T_G)-(0.01135\times T_{op}^2)+(0.00922\times T_{op}\times T_G)+(T_G\times 0.0835)$$

LPMV5=−0.2402+0.3126 × PMV+0.1289 × *TG*

The SD of the stated five LPMVs (Loughborough PMVs) and some other combination of influential parameters is presented in Figure 9. The SD of all the 3D curve fit based models (blue bars) is less than Fanger's PMV model (shown in red dotted line). It can also be seen

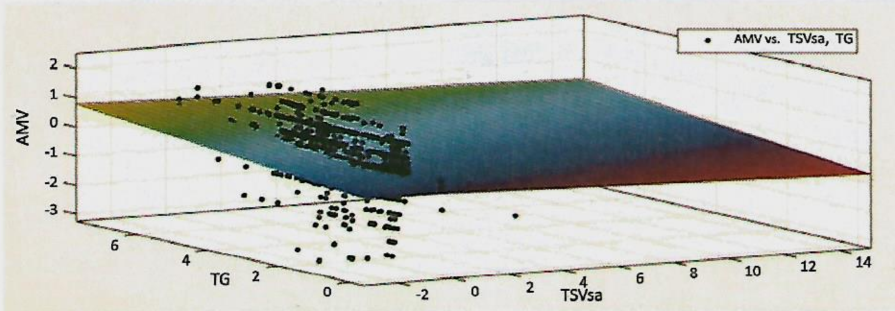

Figure 4: LPMV1 3D curve fit between AMV, TG and TSVsa.

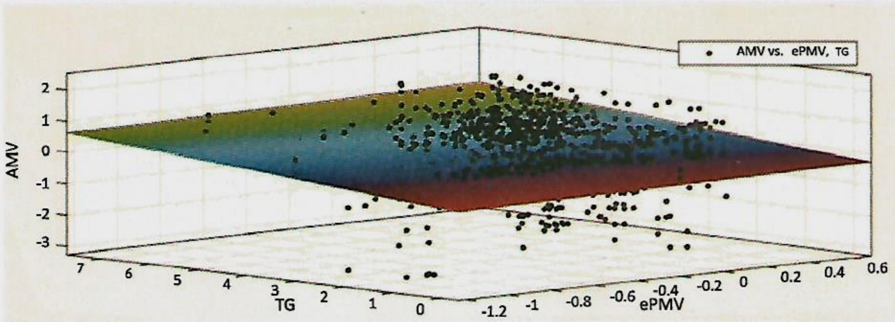

Figure 5: LPMV2 3D curve fit between AMV, TG and ePMV.

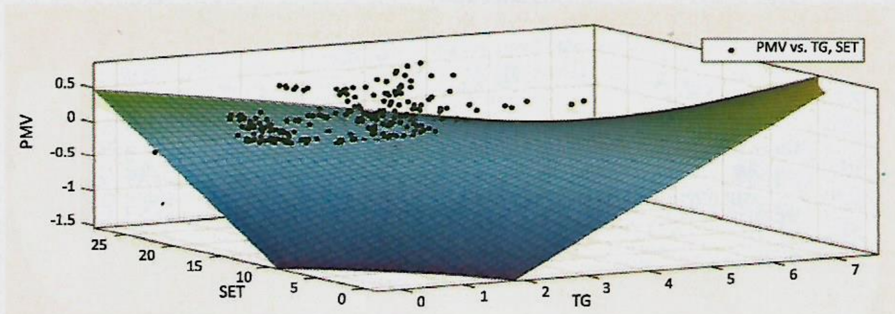

Figure 6: LPMV3 3D curve fit between PMV, TG and SET.

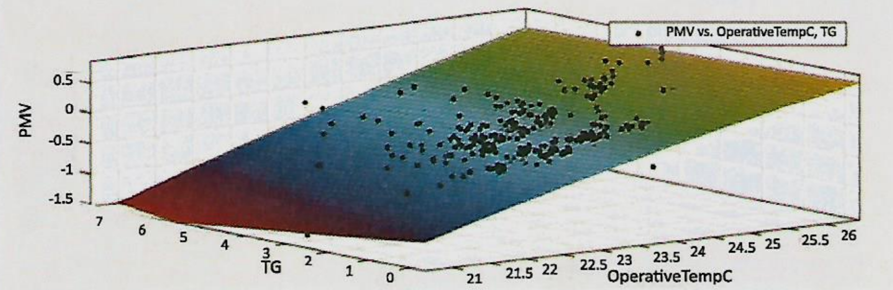

Figure 7: LPMV4 3D curve fit between PMV, TG and Top.

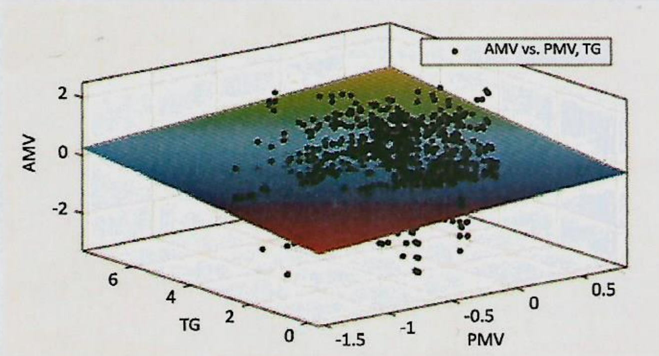

Figure 8: LPMV4 3D curve fit between AMV, TG and PMV.

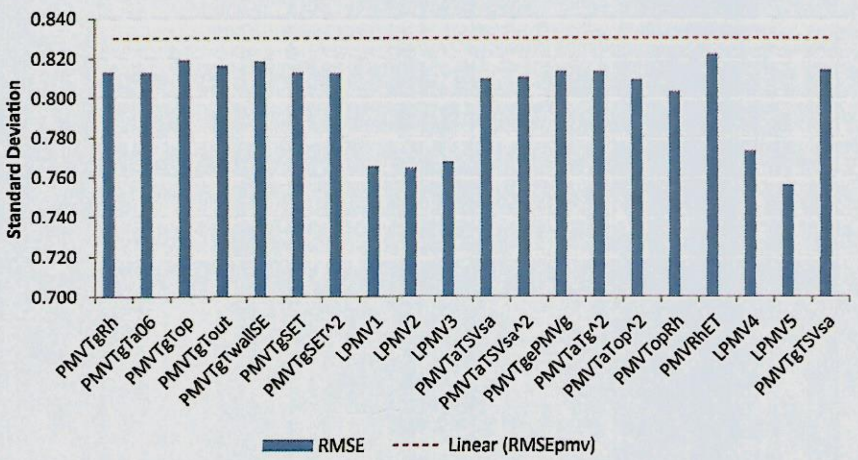

Figure 9: Standard deviation of 3D curve fit based PMV models in predicting neutral temperature compared to Fanger's PMV.

that the five models LPMV1 to LPMV5 have significantly less SD in predicting occupant's neutral temperature.

In order to conduct scientific rigour, the five LMPV models will be tested against unrelated thermal comfort data that was compiled from different experiments by other researchers in different locations in the UK. For this reason, data from the RP-884 database in South Wales and Liverpool, UK have been utilised. Figure 10 presents the comparison between the different comfort models against the Fanger's PMV model. Some of the five selected models do perform better than PMV for either South Wales or Liverpool's data. However, LPMV3 is observed to perform better than Fanger's PMV in predicting neutral temperature for both data sets. LPMV3 exhibited and improved SD of 0.1°C for the South Wales data whilst an improved SD of 0.7°C for the Liverpool data. This is a significant improvement in neutral temperature prediction and can have consequences in terms of energy use when specifying heating setpoint temperature.

Results and Conclusions

This paper presents the development of an improved mathematical model that can predict occupant thermal comfort in a residential building (specifically in a living room area). The method employed is of plotting polynomial fit curves between the most influential parameters

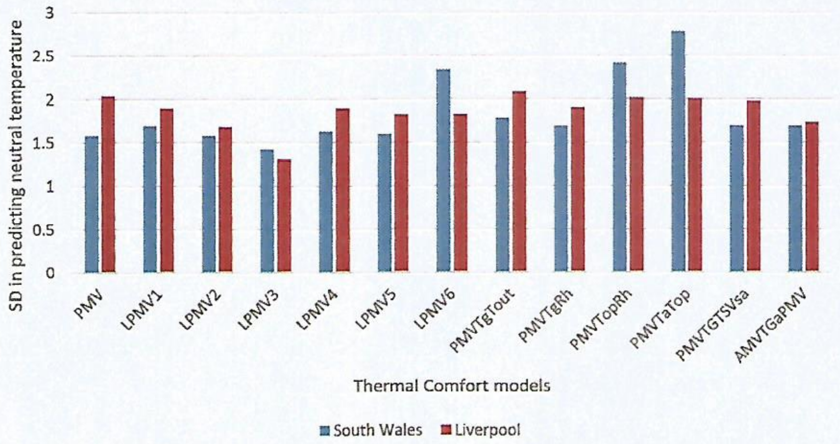

Figure 10: Performance analysis of different comfort models in predicting neutral temperatures from the Rp-884 database in South Wales and Liverpool, UK.

that affect AMV. The aim was to incorporate temperature gradient, a parameter that is usually ignored in generating comfort models. The best performing LPMV model utilises both vertical temperature gradient, TG and SET for predicting thermal comfort. It was observed that LPMV model had a SD of 0.76 compared to Fanger's PMV model of 0.83 in predicting neutral temperatures of occupants participating in this study. This difference might not be significant in this specific test scenario, but the improved model does promise better performance which might be amplified in other applications. Furthermore, the LPMV model was observed to better predict neutral temperature (0.2°C cooler) compared to Fanger's PMV model for independent thermal comfort data (RP-884 database). It needs to be noted here that this model performed better than Fanger's model for test case with high temperature gradients whilst PMV is more suited for uniform conditions. Thus, the application of LMPV is more suited for areas where high temperature gradients are expected. This can have immense effect in choosing set point temperature of the heating system and consequently the energy use. This model is recommended for use in residential houses with strong temperature gradients such as the rooms heated by radiators which are common in UK houses.

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