Colour as a Tool to Manipulate Indoor Thermal Perception in Tropical Upland Climate; A Field Experiment Implemented in Sri Lanka

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Abstract

Incorporating warm colours in the interiors of tropical uplands characterissed by a cold climatic condition, was hypothesised to help the inhabitants to perceive the indoor thermal environment as comparatively warmer, compensating the heating costs to a considerable extent.

A preliminary field experiment was executed to investigate the impact of a warm colour (red - Cranberry Zing) and a cool colour (Duck egg blue) on indoor thermal perception in tropical upland climate with reference to Thalawakele, Sri Lanka.

Substantiating the hypothesis, participants consistently perceived the red room to be comparatively warmer (90% - warm and 10% - slightly warm) while the blue room was perceived to be even cooler by 93.5% (64.5% - cool/ 29% - slightly cool) and neutral by 6.5%. Ability of red colour to induce a comparatively warm 'perceived' indoor thermal condition against the 'real' thermal condition in tropical upland climate could be potentially developed as an alternative hybrid remedy for energy conservation.

Keywords: *Thermal perception, Warm colours, cool colours, tropical upland climate, Energy conservation.*

1. Background

This is an era where innovative architectural and design interventions that focus on energy conservation have been given a greater emphasis. Amidst the diverse attempts made in innovative architectural, planning and interior design solutions aiming to cut down heating and cooling costs, starting from the orientation of the building itself to the use of passive solar design strategies, construction methods and incorporating appropriate building materials and finishes, the current investigation focuses on a simple, low cost solution.

Colours are known to play many roles in the paradigms of Architecture and Design. They have widely been used for aesthetic and visual purposes in built environments to create pleasing harmonious compositions. It has also been a usual practice to integrate the ability of colour to alter the perceived dimensions of space and objects. However, revealing another dimension of it, colour has been explained by scholars, researchers and colour therapists as to influencing thoughts, feelings, emotions and behavior. Usage of this property of color is evolving beyond its typical aesthetic value, to aid human performance corresponding to the intended activity of built spaces. Amongst diverse colour associations, the current study focuses on the ability of colour to alter human thermal perception, as a means of energy conservation.

At this juncture, it is vital to clarify that the study does not focus on the heat absorbing / heat reflecting properties of colour, which are already used as a strategy to conserve energy. As per the principles of colour theory, light colours will reflect more heat and dark colours will absorb more heat; thus, the lighter the colour, the higher will be the reflectivity of a surface. Accordingly, while white has the highest light reflectance value (LRV), black is known as the best absorbent. For instant, white reflects 80% of light, whereas black will reflect only 5%. This principle has been applied to manipulate and conserve energy to be spent on interior lighting. For instance, the higher the LRV number of the paint colour, the lesser will be the amount of artificial light needed (Morton, 2012). To be explicit, far more lighting is required for rooms with dark walls than for those with light walls and the cost of energy involved will be high. In addition to the walls, keeping the ceiling light and bright will increase reflectance to support energy conservation. Similarly, light colours applied on roofs are said to cut down cooling costs of interiors due to their high albedo. Morton

(2012) describes a study conducted in Austin, Texas on a clear, sunny day having an outdoor temperature of 90 º F (32.2 C), where a white roof had a temperature of 110 º F (43.3 C), an aluminum coated roof, 140 º F / 60 C, while a black, single ply roof, a temperature of almost 190 º F / 87.8 C. As further highlighted by Morton (2012), another study in Florida revealed that by increasing heat reflectivity, homeowners saved an average of 23% of their cooling costs. Accordingly, the LRV value of a coloured surface has been established as a decisive factor for energy conservation. The current study focuses on a different aspect of colour, potentially conducive for energy conservation; the ability of colour to alter the perceived temperature.

1.1 Supportive Literature

Mahnke (1996) states that colour can be identified in terms of temperature. As explained by Candas and Dufour (2005), thermal perception could be created by the visual appearance or the colour of an object. Moseley and Arntz (2007) explain that colours have the power to endorse an implicit meaningful association in relation to temperature; typically, red is linked to "hot" while blue to "cold".

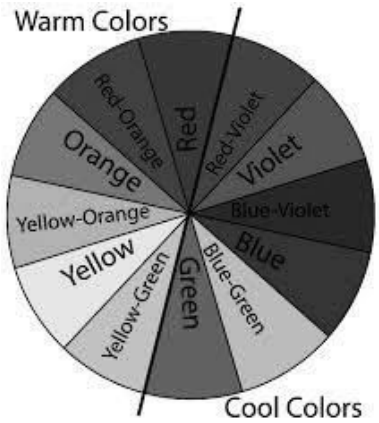


Figure 1: Warm cool division in the Colour Wheel

Traditional colour theory distinctively differentiates between warm colours and cool colours to have opposite psychophysiological impacts upon humans. Red, orange and yellow are identified as warm colours which are stimulating, while blue, green and purple are referred to as cool colours with pacifying effect on human beings (Stone 2001, Ballast 2002).

Compared to the research conducted on diverse colour associations, scientifically or statistically substantiated research data on the nature of colour associated thermal perception is inconclusive. In his book "Colour environment and human response", Mahnke (1996) explains the warm/cool perception of colour as a synesthetic response; the unity between two different sensory modalities. This simply suggests that every sense is linked with each other. Moreover, he explains that colour perception is simultaneously linked with other perception modalities such as weight, volume, size, temperature, noise, sound, etc. As suggested by Mahnke (1996), colour has the power to suggest warmth or coolness as a manifestation of a synesthetic response.

On the other hand principles of colour therapy explains the possibility of colour in altering human body temperature as a result of a metaphysical reaction. This is considered as a possible reason for the perception of certain colours as warm and vice versa. For instance, while Manuel (2011) suggests that colour red can increase one's energy level and raise the body temperature, Lung (2011) proposes that the colour blue lowers the pulse rate and decreases body temperature. In a recent study, Hettiarachchi (2014) investigated the logic behind colour associated thermal perception with reference to colours red and blue in a controlled laboratory environment (26ºC/ 50% rh /350 lux). This study revealed that psychological parameters were statistically significant against the parameters of actual thermal sensation and core body temperature. Mahnke (1996) mentions that people are found to be fairly unanimous in their opinion of warm/cool perception regardless of how it takes place.

Scholars who have attempted to provide scientific evidence for theory of warm and cool colours are minimal. Mahnke (1996), the president of international colour association, has cited a few previous researchers who have provided supportive evidence for the perception of colour in terms of temperature. A study done by Johns Itten (1961, cited in Mahnke, 1996) demonstrated a difference of 5 - 7 degrees in the subjective feeling of heat or cold between a workroom painted blue-green and one painted red- orange. Occupants of the blue-green room felt 59 ° F as cold, whereas the temperature had to fall to 52 ° F in the red- orange room before the subjects felt cold. Clerk (1975) reported that employees complained of the coldness in an air-conditioned factory cafeteria with light- blue walls, although the thermostat was set at 75 ° F. The walls were repainted orange and the 75 ° F temperature setting, then considered too warm, was reduced to 72 ° F. In a Norwegian study, subjects tended to set the thermostat 4 degrees higher in a blue room than in a red room (Tom and Micelles, 1976). Further strengthening this ideology, Morton (2012) reports on tests in which people estimate the temperature of a room with cool colours, such as blues and greens, to be 6 -10 ° F cooler than the actual temperature. Warm colours, such as reds and oranges, will result in a 6-10 ° F warmer estimate. Accordingly, a few scholars have yielded supportive evidence for the ability of colours to alter thermal perception of an interior.

However, as identified by Gage (1995), the usage of colour associated temperature in prescribing colours have always been a matter of debate and puzzlement. The lack of knowledge on the nature of manifestation and the contributing factors of colour associated thermal perception are the main causes of obstruction in its effective integration to man-made environments.

Going in line with the few supportive findings, the current study attempts to seek the possibility of integrating colour as a tool to conserve energy in cool climatic regions. A recent investigation executed by Hettiarachchi (2014), revealing this association to be a psychological reaction, firmly suggested the potential of the warm cool dichotomy of colour perception to be integrated in the built environment to 'psychologically manipulate the occupant's perceived thermal milieu against the actual thermal conditions', which could eventually contribute as an alternative remedy for energy conservation. Consequently, the research design of the current investigation was formulated based on the principle that the perception of warm/cool colours is a psychological reaction.

Building interiors are mostly designed integrating warm colours as an influence of the traditional British practice, molded and fashioned by cold climatic conditions. In fact, the inhabitants of Britain, by default, demand warm colours in their interiors and reject cool colours (Perera, K, personal communication, July 8, 2014). Even though not established in literature, this provides inspiration for an unconscious psychological response, accumulated throughout the course of time and converted into a practice to counteract the cold climatic conditions, using the perceived thermal aspect of colour where a psychological thermal comfort is achieved. As mentioned by Mateeva, 2011, it may be expected that people with long-lasting adaptations to hot climates have lower sensitivity to them and higher sensitivity to cold climates, and vice versa – people durably adapted to cold climates have lower sensitivity to them and higher sensitivity to warm climatic conditions. Accordingly, it can be proposed that the inhabitants of cool climatic regions could prefer the stimulating, warm psychological impact of warm colours against the cool, pacifying impact of cool colours and very sensitive/ responsive towards warm colours.

To highlight a parallel approach, Albers et al (2013) attempted to test colour in the form of light; warm/cool coloured LED lighting scenarios to conserve energy in the aircraft/aviation industry. Subjects reported slightly warmer thermal sensations in yellow light and slightly colder sensations in blue light demonstrating a slightly higher level of satisfaction with the climatic situation in yellow light. As revealed by Albers et al (2013), even though the impact of lighting on temperature and comfort sensation is minimal, large scale utilization could potentially contribute to a quantifiable impact on energy savings. Similar impacts could be anticipated by the integration of colour in the applied form (paints/pigments). Supportively, Morton (2012) has suggested that "Colour does play an important role in energy conservation".

1.2 Hypothesis

The current study hypothesized that warm colours (red), integrated in interiors of cold climatic regions, will make the inhabitants perceive the interior as warmer than the actual thermal condition, while cool colours (blue) in the same interiors will make them feel even cold.

1.3 Aims and objectives

This research attempted to test the above hypothesis via a field investigation. The findings of the study can be helpful on one hand to architects, interior designers, and landscape designers, interested in methods of improving thermal comfort of interiors in cold climatic environments. On the other hand, this will provide insight to recognize colour as another factor which should be considered in the process of formulating energy efficient design strategies. For instance, it is expected here that warmer thermal perception, psychologically induced by a warm colour may compensate the energy to be spent on heating the interior to some extent; a hybrid remedy for energy conservation.

2. Method

Personalized houses possess familiar spaces of human beings, to which they are highly sensitive than any other space. Therefore, the simplest alteration done in one's own home may have a great impact on his/her perceptions and psychophysiological responses. An alteration in one's most personal space such as the bedroom may have a predictable impact on its user in this regard. Accordingly, the design of the current field investigation was focused on altering the colours of bedrooms to test the impact on thermal perception. Talawakele, a town located in the Nuwara Eliya district of the central province of Sri Lanka was selected (mean annual temperature -18°C) representing the tropical upland climate characterized by a comparatively cold thermal condition.

Figure 2: Location of selected houses -Google map – Upper Kothmale hydropower project Housing scheme

Figure 3: View - Upper kothmale hydropower project Housing scheme

2.1 Research Design

Figure 4: View of a sample house

A sample of 7 nos of identical houses from a housing scheme having the same plan and identical method of construction, materials and finishes constructed under the upper Kothmale hydropower project were selected to execute this field investigation. Being adjoining houses located in the same locality all the climatic factors; solar radiation, outdoor temperature, humidity and air velocity pattern remained same. In these selected seven houses there were 31 participants of varying age groups representing both genders (17 males and 14 females). Two identical bedrooms having the same dimensions, and fenestrations (a door and a window in each) were selected to apply the colour. The colours to be tested were proposed to be applied on an identical wall per room; a warm colour on one wall and a cool colour on the other (Figure: 5) while the other three walls were proposed to be painted in brilliant white (Figure: 7, 8, 9). This decision ensured that the two rooms to be tested are identical in every aspect other than the introduced red or blue colour.

2.2 Colour Selection and application

A red hue was proposed to be tested as the warm colour based on the stimulating effect of the colour identified in theory of colour. Even though red in its full intensity will induce the greatest impact, considering the ethical fact that this colour is to be applied in a house occupied by human beings, and the new colour scheme is proposed to be remained unchanged until the next colour wash to be done by the occupant, a de-intensified version of red (*Cranberry Zing)* was specified. On the other hand, being the most recognized colour representing the cool paradigm of the colour wheel, a blue hue was proposed to be tested. Considering the accepted cooling and sedating effect of the colour found in colour theory, despite using blue hue in its full intensity a de-intensified version of blue was selected from the colour manufacturer *(Duck Egg Blue).* The specified colours were shown to the respective house owners and their consent was obtained prior to the application, fulfilling ethical concerns.

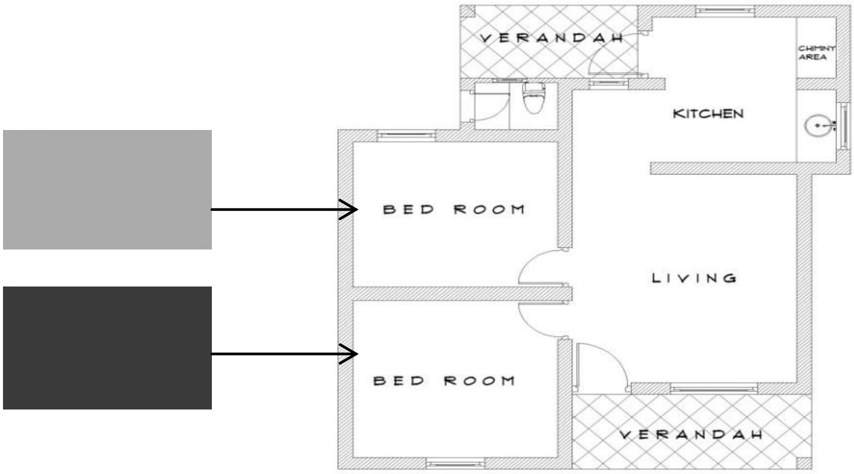


Figure 5 - Layout of a house

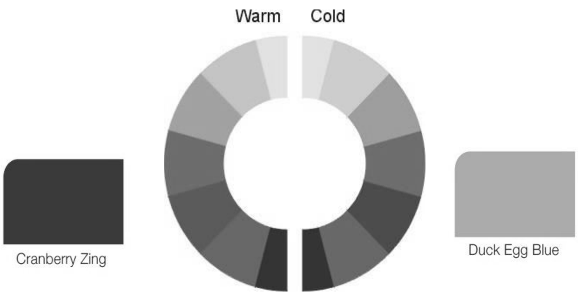


Figure 6: Colours specified to represent the warm and cool paradigms of the colour wheel

Figure 7: Canberry Zing, brilliant white and duck egg blue before application

Figure 8 - Colour application process

Precise instructions on the colour application process were provided to the house owners and, all the seven houses were coloured simultaneously with their involvement under the supervision of the investigator. This can be identified as a win-win situation where these seven houses were painted free of charge.

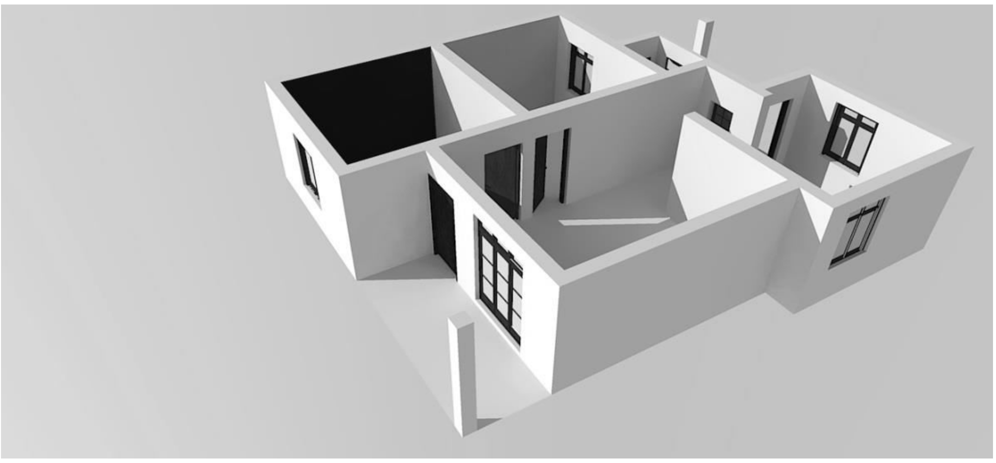


Figure 9 – 3D view of the identical bedrooms after colour application

2.4 Data collection

At the onset of the investigation, favorite colour/colours of the participants of each house were inquired to test the possible impact of long term exposure to a cold climatic condition on colour preference. It was expected here that, residents in a cool climatic region might prefer warm colours against cool colours due to its perceived warm thermal impacts.

Once the new colour scheme was applied, the subjects were requested to occupy the rooms for 24 hours to follow their normal routine while getting exposed to the new colour scheme. Following the new colour exposure, the subjects were interviewed to identify their general response; attitude, feelings emotions towards the new scheme and the effect of red/blue colours on their thermal perception of the interior.

The main data collected was the possible difference of thermal perception of subjects associated with new colour scheme with reference to the two bedrooms; red room and blue room. The subjective perceptions were transformed into objective data with the use of a 5 point likert scale which is a reduced version of the PMV scale (Fanger, 1970).

Figure 10: Likert- scale questions Source: PMV scale (Fanger, 1970)

The indoor temperature of red vs blue rooms in all the 7 houses against outdoor temperature were monitored via a digital thermometer.

3. Results and Discussion

Research findings revealed by the questionnaire are graphically presented below.

3.1 Favourite colour

Question answered: What is your favorite colour? (Blue, Red, Green, Yellow, Purple, pink, white, black…………)
Other suggestions if any………….

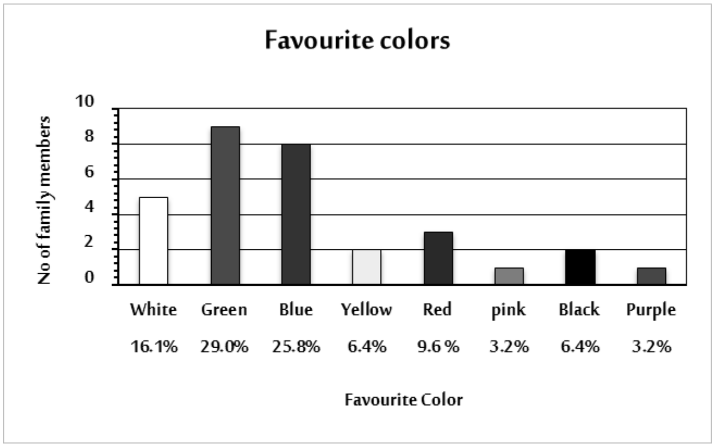


Chart 1 – colour preference

Note: The majority (58%) selected cool colours (Green, blue and purple) as their favorite colours while 22.5% liked neutral colours (Black and white) and only 19.2% selected warm colours (Red, yellow and pink) as their favourite colours.

3.2: Perception of new colour scheme vs. Previous colour scheme

Question answered: Did you feel any difference between the new colour scheme and the previous colour scheme? (Yes / No / Neither) Other suggestions if any……

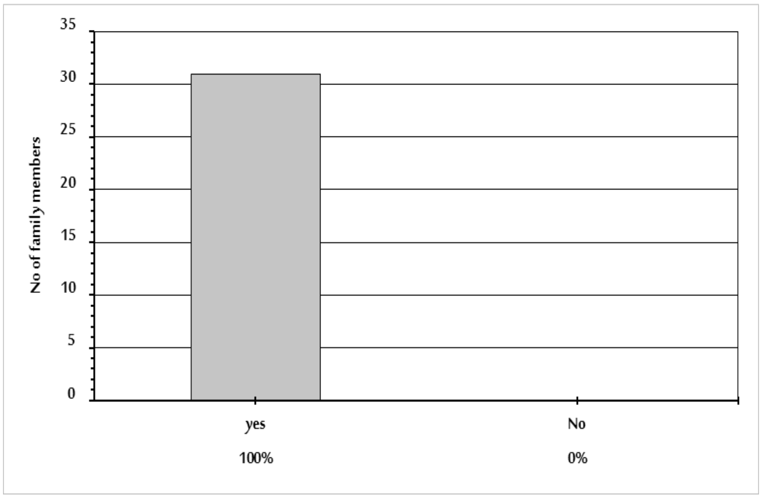


Chart 2: Perception of new colour scheme vs. Previous colour scheme

Note: 100% perceived a difference between the previous and the new colour schemes.

3.3 Type of the perceived difference between new and the previous colour scheme

Question answered: What type of a difference did you feel from the new colour scheme? (Positive, neither positive nor negative, negative)

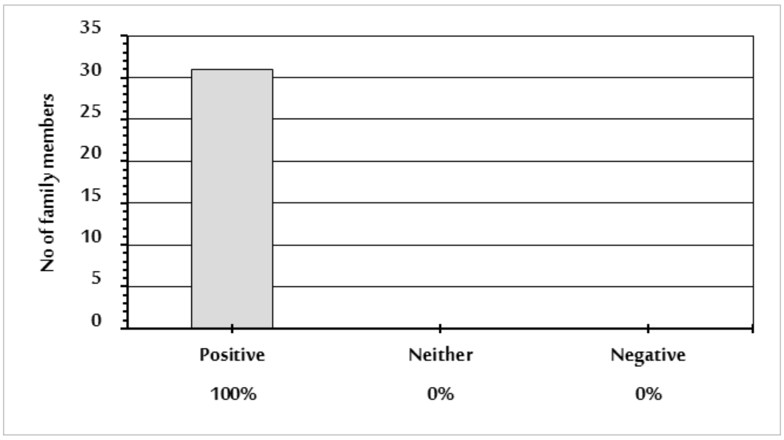


Chart 3: Perception of new colour scheme vs. Previous colour scheme
Note: 100% were positive with new colour scheme.

3.4 Spontaneous thermal perception in general

Question answered: Did you feel any variation in thermal perception associated with the new colour scheme? (Strongly agree /agree/ neither/ Disagree/Strongly disagree) Other suggestions if any…….

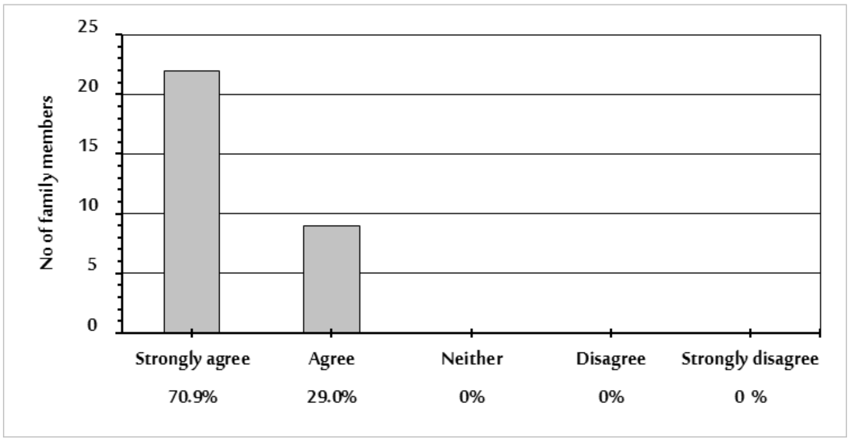


Chart 4: Spontaneous thermal perception in general

Note: Being on par with hypothesis, majority (99.9%) regardless of the variations of age and gender felt a thermal perception variation in new colour scheme against the previous. Most of them agreed (99.9%) that they felt a difference in room temperature especially during the night time.

3.5 Thermal perception associated with red (Cranberry Zing) room.

Question answered: Describe your thermal perception in the red colored room?
(Warm / slightly warm / neutral / slightly cool / Cool)

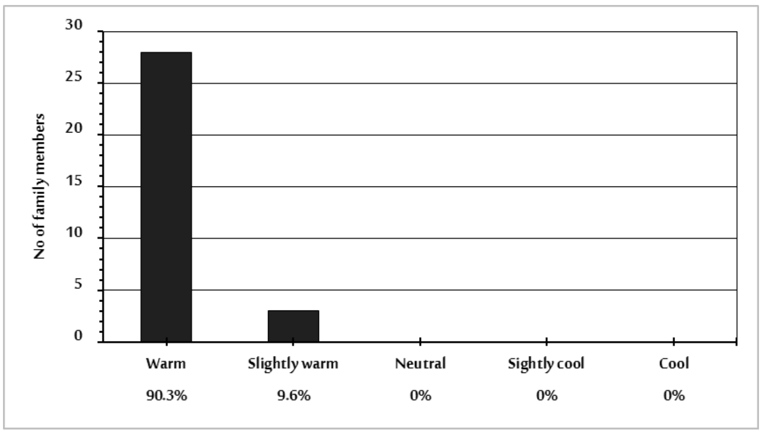


Chart 5: Spontaneous thermal perception in general

Note: A majority (99.9%) of participants perceived red room to be warmer (90.3% strongly agreed and 9.6% agreed).None of them perceived it to be cooler.

Few noteworthy comments made by the participants of the seven houses on the impact of colour red in general and associated thermal perception are quoted below.

A young boy (18 yrs.) of house two – *"I feel that my bed room is warmer than what I felt before due to the introduction of red colour"*

A boy (13 years) of house five – *"I slept well than previously in my red coloured bed room, because of its warmth"*

Old person (64 years) in house four – *"I got muted when I saw the red room at once"*

A lady (42 years) of house six (a Hindu family) – *"We like red coloured room as red is very much closer to our religion"*

On the other hand as a significant finding, the participants highly preferred the red room suggesting their sensitivity to colour red.

3.6 Thermal perception associated with blue (duck egg blue) room.

Question answered: Describe your thermal perception in the red colored room? (Warm / slightly warm / neutral / slightly cool / Cool)

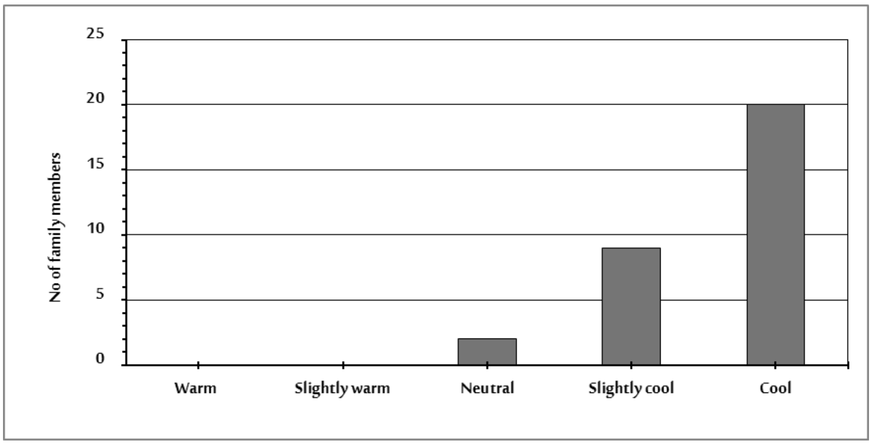


Chart 6: Spontaneous thermal perception in general

Note: A majority (93.5%) perceived blue to be cool (64.5% strongly agreed, 29% agreed) and 6.4% remained neutral. None of them perceived the room to be warm.

Two interesting points which the author noted among the comments made on the impact of colour blue in general and on thermal perception are attached below.

A young girl (20 yrs.) in house two – "*I felt very uncomfortable last night in blue room, because it 'was very cold than previous days."*

A lady (59 yrs.) in house two – "Blue is a beautiful colour, but I like red coloured interior"

Accordingly preference to the blue room was less compared to the red room.

3.6. Preference comparison -* Cranberry Zing room *vs. Duck egg blue room.

What is the room that you prefer most in terms of the colour scheme?
(Cranberry Zing room/. Duck egg blue room)

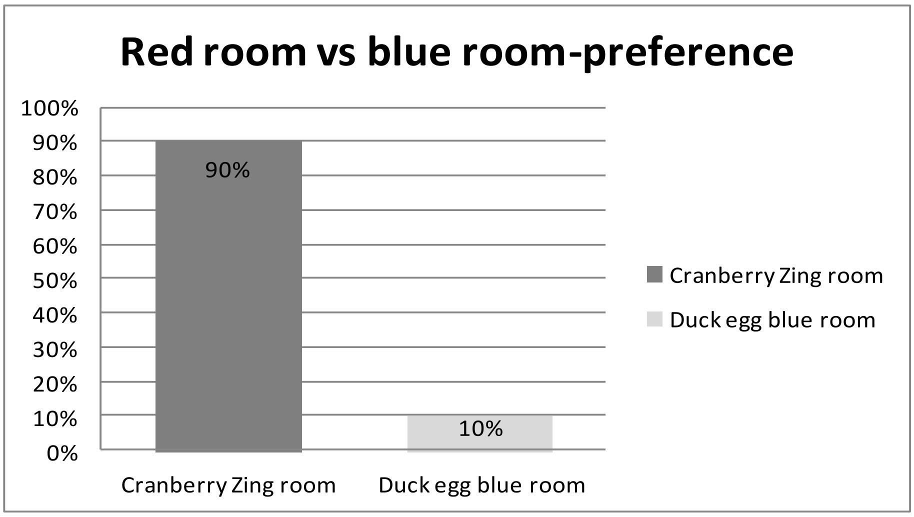
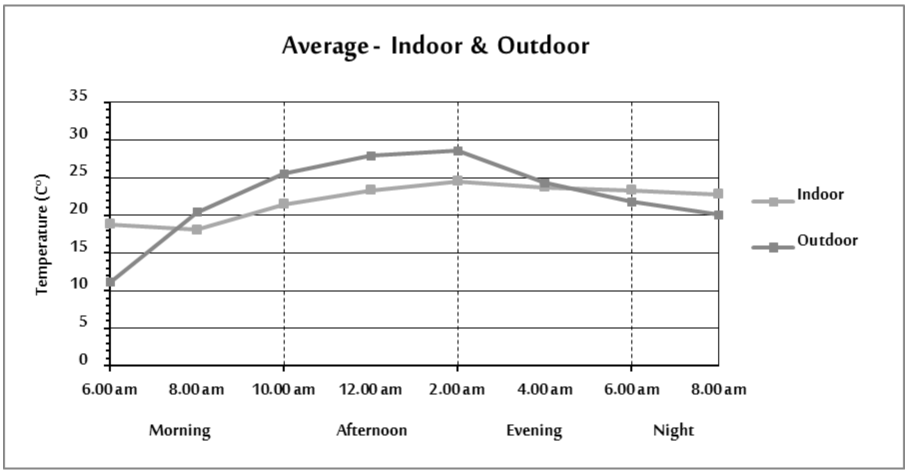


Chart 7: Preference – Red room vs Blue room

Note: The majority of participants preferred the red room most (90%) whereas only 10% preferred the blue room.

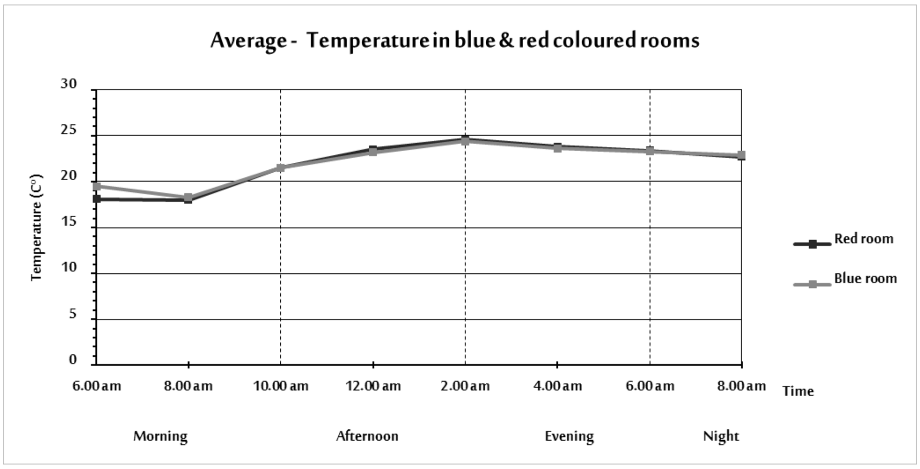
3.7 Average indoor and outdoor temperature.

Note: The indoor temperature was found to be higher than outdoor temperature in the morning while the extreme opposite reaction was reported during the day time. As shown in the graph below, indoor temperature increased gradually while the outside temperature decreased rapidly with the night fall.



Graph 1 – Average indoor / outdoor temperature

3.8 Average temperature of blue and red coloured rooms



Graph 2 – Average temperature red vs blue

Note; No significant difference between the indoor temperature of rooms having a red wall and a blue wall was reported even though the inhabitants perceived red room as warm and blue room as cold.

4. Analysis and Conclusions

When it comes to the colour preference of the participants, it was revealed that cool colours were dominating as their favorite colours (58.0% - green, blue and purple) while 22.5% selected neutral colours (black and white) and only 19.2% selected warm colours (Red, Yellow and Pink) as their favorite colours. Warm colours were not dominating as their favorites as anticipated by the investigator. This preference to some extent can be as a result of long term psychophysiological adaptation, acclimatization and familiarization to a cold climatic condition characterized by a cool pacifying ambience.

All the participants of the seven houses involved (100%) were positively responding to the new colours in their bed rooms. This however could be explained as a common psychological reaction to a new change applied within a long existing situation, especially in terms of a colour scheme. However considering their personal comments as well as the spontaneous reactions triggered by the two new colour schemes applied, it was revealed that even though a majority possess a cool favorite colour, they were much sensitive and responsive to red room against blue room (Red - 90%, Blue – 10%). They remarkably preferred red room and showed a lesser interest on the blue room. As the underlying reason for this finding, it can be suggested that people who are psychophysiologically adapted to cool climatic conditions in long term basis would be very much sensitive and prefer warm conditions than the usual cool conditions so does their response to a warm colour vs. a cool colour.

Substantiating the hypothesis, it was revealed that the participants significantly perceived a change between the new and previous colour schemes in thermal terms (70.9% - strongly agreed and 29.0% agreed). Regardless of the participants age or gender, the majority consistently (99.9%) perceived red room to be warmer (90.3% strongly perceived and 9.6% perceived).On the other hand 93.5% perceived Blue room to be cooler (64.5% strongly perceived and 29% perceived while 6.4% remained neutral). Also no significant difference between the indoor temperatures of red room vs blue room was identified by the investigation. This finding substantiates the ability of colour red (warm colours) to induce a warm perceived thermal ambiance regardless of the actual cold thermal condition. This is a positive association which can be used to create habitable interiors in cold climatic conditions contributing to a thermally comfortable better living environment. Supported by the psychologically induced warm thermal perception, introducing warm colours to a cool climatic situation will make people more active and energetic to counteract the cool pacifying ambiance. This in turn will allow them to reduce the heating cost to some extent in the interiors where a heating system is used. On the other hand the study reveals that integrating cool colours in the interiors of a cold climatic condition works negatively as the participants perceive the interior as even cooler than the actual condition making the situation even worse. This will unnecessarily increase the heating cost. It is also suggestive that cool colours can be similarly integrated to manipulate thermal perception in other tropical conditions namely humid, hot, dry…ect.

In conclusion, this study identifies colour as a most potential tool to manipulate the perceived thermal ambience in interiors of cold climatic regions. Significantly, the study recommends integrating warm colours when designing interiors in cold climatic regions to create a thermally comfortable environment while discouraging the use of cool colours. Further it is recommended to develop the research design with reference to interiors where a heating system is involved to test the possibility of energy conservation as a future direction. It is also suggested to test the reverse principle of integrating cool colours to create thermally comfortable interiors in hot humid/dry climatic conditions eventually contributing to saving of cooling costs.

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Selection of Sustainable Composite Partition Material for Sri Lankan context

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Building materials are deemed to play a vital role in increasing buildings sustainability while contributing to the economic prosperity. Usage of large quantity of non-renewable resources in the building materials has a major impact on the environment, depriving future generations of its usage. These building materials are used to construct diferent types of building element. Thus, it is believed that the appropriate selection of building materials for different purposes is one of several factors that contribute to sustainability within the built environment. However, traditionally the selection of such materials depends on consensus-based understanding of environmental issues in designing and construction of facilities. On this note, this study investigates the most suitable composite material that can be used for partition wall construction in Sri Lanka with respect to sustainable parameters. The research is quantitative in nature where a preliminary market survey and a subsequent questionnaire survey were conducted to identify the available materials used in partition wall and evaluate the materials' performance, in terms of embodied energy, toxicity, locally produced material, price, maintainability, aesthetics, resistance and durability respectively. The questionnaire survey was administered to 35 professionals (Architects, Engineers, Quantity Surveyors and Facility Managers) practicing in the construction industry. In order to compare the materials pair wise, an Analytic Hierarchy Process (AHP) based on was employed.

Research findings show that Medium Density Fibre (MDF) board, Gypsum Board (GB) and paddy straw composite board (DURA) are alternatives of composite partitioning materials. In terms of embodied energy (EE), Cost (C), toxity (T), natural and local available materials (N&L) and maintainability (M) with recieving a relative weight (RW) of 0.471, 0.487, 0.420, 0.398, 0.339 Dura board is preferred over the other materials. However, in terms of aesthetic (A) and resistance (R) criterions with obtaining a RW of 0.414, 0.421 GPD board serves better than other materials. MDF board is at the top in terms of durability with a RW of 0.351. When the overall performance is focused, DURA offers the best value while MDF and GPD board occupy the next places respectively. This study, therefore identifies the most suitable composite alternatives to assist professionals in the selection of most suitable materials for partition walls in Sri Lanka.

Keywords: *Partitioning, composite materials, sustainability, construction, Sri Lanka.*

1.0 Introduction

Within the past couple of decades, the world has changed with an ever-increasing recognition that the mankind can no longer continue to use natural resources without facing the environmental consequences (Kibert, 2005). This has led to the enhanced concern of the protection of environment in which construction activities take place where sustainable construction has been hailed as a way forward to eradicate the adverse impact on the environment (Asad & Khalfan, 2007). Mora (2007) states that in the perspective of construction, buildings have a profound impact on the environment and even a small change in their sustainability can create a major reduction in the current ecological footprint of the whole society.

Further, Haggag and Elmasry (2011) highlighted that the materials used in building constructions are one of the key areas of architecture to achieve sustainability in the built environment. These materials used for constructing building elements and obtained from the local resources with the help of renewable materials like recycled materials, coral stone, agro waste, etc. If these materials used locally then it may add value to the development of the economy and lead to sustainability while enabling the citizens to have economically benefited. The growing interest in sustainable buildings and the great demand for its profitability in the long run such as improved quality, enhanced durability, enhanced occupational health and safety, material conservation, less construction site waste and less environmental emissions (Chen, Okudan and Riley, 2010) etc has led the researcher to identify alternative sustainable building materials to build building elements.