The Correlation between Colour associated Thermal Perception and Preferred Human Activity

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Abstract

Research has shown that colour stimuli could trigger certain fixed emotional and behavioural responses within human beings. Consequently, transcending its typical aesthetic value, colours have a greater potential to be integrated into design in a way that can stimulate required emotions and behaviour in the built environment to enable optimum human performance. This attribute is identified in the present study as an important aspect of the 'functional value of colour'. Literature on theory of colour explains the relationship between colour and human's thermal perception (TP), distinguishing warm colours (red, orange, yellow), cools colours (blue, green, purple) and neutral colours (white, grey, black). This study emphasises that every human activity demands a unique thermal condition or environment for its optimum performance. In consequence, it was hypothesised that colours could be potentially used to manipulate human thermal environment as demanded by the activity intended in any built space. Hitherto, the scientific investigations done on the nature and potential of this association are scarce. The present research attempts to provide evidence for TP related to a few selected colours, while identifying certain associated functions for aforementioned colours.

A group of normal sighted, healthy volunteer undergraduates (n=72) of the same age (20-23) were shown computer generated slides of a typical room in seven different colours as specified in RGB colour model, projected on to a wall ; red(255,0,0), orange (255,165,0), yellow (255,255,0), blue (0,0,255), green (0,128,0), purple (128,0,128), white (255,255,255) within a controlled studio environment. While maintaining a constant ambient temperature (26^{o}C), the participants were exposed to each slide for two minutes. They rated their thermal perception (warmness/coolness) of each room on a 5-point likert scale and selected activities they would prefer to perform, in each room out of a list of activities provided to them, imagining that they were actually experiencing each coloured room shown in the slides. Findings of this study provide testimony for colours' ability to alter human's thermal perception. Explicitly, TP of red, orange and yellow colour slides were rated as warm and blue, green, purple slides were rated as cool while white slide was found to have an average TP. Red was found to trigger the highest TP and blue, the lowest TP. The following relationship between TP of the seven colours tested was arrived at; TP Red > TP Orange > TP Yellow > TP White > TP Purple > TP Green > TP Blue.

Supporting the hypotheses, the participants preferred to perform active functions in the rooms which they rated to have a high TP and vice versa. For instance, red room was preferred for exercising and sports, while orange was selected for sports, dining and exercising. Yellow was imagined as suitable to support discussions, dining and sports. The colours identified to have a low TP were significantly preferred for calm activities. Blue and purple respectively were decidedly preferred for sleeping and secondly for relaxing. Green room was dominantly preferred for relaxing. White which was rated to have an average TP was chosen for calm and neutral activities, mainly drawing, reading and meditation.

Key words: Functional value of Colour, Thermal Perception, RGB colour Model,

1.0 Introduction

Since ancient times, colours have been utilised all over the built environment for its well distinguished aesthetic and beautification value. The present study gives emphasis to the ideology that a colour scheme while being an aesthetically pleasing harmonious composition, should aptly support the proposed function of any built space facilitating optimal human performances. Researchers reveal that colour stimuli can trigger corresponding intrinsic emotional and behavioural responses within human beings. Transcending beyond the renowned aesthetic value of colour, the above association has greater potential to be utilised logically and meaningfully to enhance human activity in the manmade world. The use of colour to support human activity in built spaces is identified in the present study as a main aspect of the 'functional value of colour'. Of the diverse emotional and behavioural responses triggered by colour, the present study will be limited to colours associated with the thermal perception of human beings. To be precise, it is a preliminary investigation done to provide scientific testimony for colour associated with human thermal perception and its possibility to support human activities.

Colour theory, though not substantially supported via scientific research, explicates that certain colours; reds, yellows and oranges, are perceived by humans as warm while blue, green and purple hues are perceived as cool leading to the principle differentiation between warm and cool colours. This study attempts to establish the postulation that each colour could trigger a corresponding fixed thermal perception. It's hypothesised that each activity demands a particular thermal level/environment for its optimum performance. Accordingly, it has been attempted to testify the ideology that colours can be used to manipulate the required thermal environment demanded by human activities. As a consequence, the study suggests that colour could be potentially used to cut down energy costs of heating and cooling, via integrating relevant colours as per the required thermal environment demanded by the functions.

This paper at the onset will provide evidence from supportive literature on the nature and emergence of colour associated emotional and behavioural responses in general. Secondly it will zoom in to the emerging means of integrating the above association to support human functions in the built environment via available supportive literature. Moving in to the main research focus, the paper will discuss the relationship between colour and human thermal perception and its potential to be integrated to support human behaviour. To conclude, a research carried out by the author in search of scientific evidence for colour associated thermal perception and the corresponding preferred functions of a few selected colours will be brought to light.

2.0 Background: Functional Value of Colour

According to physics, colour is electromagnetic energy. Each colour is an electromagnetic energy wave oscillating at a unique frequency and wavelength. Every colour will have its unique effects on human beings determined by its corresponding wavelength and frequency. The functional value of colour in the built environment goes beyond its aesthetic value and has many functions based on the myriad effects of colour on human beings. For instance, being an inseparable element of space, colours are being used to convey meanings, ideas or concepts associated with built spaces in order to strengthen the intended message or the expression. They are used as symbols, signals, expressive agents and to convey massages, facilitate orientation and assist memory (Rihlama 1999). Good colour design is an essential factor in the communication between human beings and architectural space (Meerwein, Rodeck & Mahnke 1998). Colour can differentiate, contain, unite, equalize, and emphasize the design elements of a space (Daggett, et al, 2008).Further; it will function as means of altering the perceived dimension of space. Colours are used to change the impressions of surfaces and spaces (Rihlama 1999). The room surface colour has an impact on the impression of width, height, and depth as well as on more global attributes such as the spaciousness of the room (Neufert & Kister, 2005). Then again, colour can be used logically to manipulate the visibility of objects in the milieu; to dominate and get attracted or to recede and camouflage. The warm colours will advance in space while the cool colours will recede. Explicitly, warm coloured objects appear closer and emphasised in space while cool objects will be de-emphasised and receded (Ham1992). As explained by Daggett et al (2008), warm colours can be used to reduce the scale and size of large spaces, making them more intimate while cool colours visually enlarge a space, making it less confining. Finally and most considerably, colours are used as psychological, physiological or physical agents (Rihlama 1999). In other words colours can be integrated effectively to trigger and manipulate human emotional and behavioural responses as required by the intended function/purpose of any built space.

Therefore, use of colours in a built space could clearly go beyond its usual aesthetic value. The current study will be limited only to the latter and will be focused on the use of colour associated emotional and behavioural responses to support human activity/ performance.

2.1 Emergence of Colour Associated Emotional and Behavioural Responses

The literature available on the nature and emergence of colour associated emotional and behavioural responses provide divided opinion contributing to three principle suppositions. Common theory is that it is a learnt response which is highly subjective and varies as per the individual. Accordingly, each individual may react differently to a particular colour based on memories and experiences gathered via exposing to a particular socio cultural, religious setting in which she/he was brought up. Naz and Epps (2004) explicitly clarify that a colour-related emotion is highly dependent on personal preference and ones past experience. They further explain that colour convention differ from one society to another. For instance, mourning at death is a common emotional reaction among humans, regardless of socio cultural limitations. Even though, the usage of colour to mourn for dead people differ as per the norms learnt from each culture. Colour of mourning in most of the eastern countries including Sri Lanka and China is white. Leopold (1895) elaborates that black is the accepted mourning colour throughout Europe. Ancient Egyptians mourned in yellow while pale brown is the Persian colour of mourning. For inhabitants of Ethiopia it is Grayish brown and in Syria and Armenia it is sky blue (Leopold 1895). On the other hand, it is discussed that colour- human associations is an innate, fixed response generally having universal implications. The emotional response to colour has been found to be quite consistent although there are individual and cultural differences (Oyama, Tanaka and Chiha 19 62: Kastl and Child 1968: as cited in Bellizzi, Crowley and Hasty 1983). Man's reactions to colour are not due solely to cultural training, but to deeper lying reasons (Birren 1969). Humans have a basic biological reaction to colour and that 'the psychological reaction to colour does not preclude the basic biological reaction that stems from human evolution (Engelbrecht 2003). Specific colour stimulation is accompanied by a specific response pattern of the entire organism (Goldstein as cited in Birren1969).

Accordingly, each colour is found to trigger corresponding fixed responses in humans. For instance colour red is found to be stimulating (Nakshian 1964, Kandinsky 1977, Babbit 1878, Bellizzi, Crowley and Hasty 1983, Stone 2001) while blue is calming (Birren1969, Babbit 1878 and Stone 2001). Depending on the strength of the hue, blue is associated with emotions ranging from sedate tranquilly to a suppression of feelings (Bellizzi ,Crowley and Hasty 1983). Schauss (1981) reported that a certain shade of pink; 'Baker Miller' pink has a measurable and predictable effect on reducing physiological variables associated with aggression in subjects of normal intelligence. Babbit (1878) identified yellow and orange as nerve stimulants. Wohlfarth (1985) revealed that painting classrooms in yellow increases self-esteem of students and decreases in measures of sadness, aggression and absenteeism.

The third supposition identifies that colour associated emotional and behavioural responses to be a complex, combined effect of both learnt and innate responses. How colours are perceived varies to some extent according to ethnic origin, age sex and then psychological phase of development, but mainly people react in the same way (Rihlama 1999). As per the in-depth analysis of Mahnke (1996) a multitude of factors work together in the process of emotions triggered by colour stimuli both on a conscious and an unconscious level. Thus, colour experience cannot be definitively systematized or classified. Mahnke further identifies six interrelated layers that influence this experience which he demonstrates in a "Colour experience pyramid". The bottom layer of the pyramid which forms the firm basis for above association comprises of inescapable innate biological reactions which are beyond one's control. The associations from the collective unconscious, which are primordial and connected to the mankind's entire experience since their origin on the planet can be found in the next level. This association, similar to biological reactions, are not controlled or caused by the intellect or conscious rational thought based on personal experience amassed during our lifetime. The rest of the layers from bottom to top represent all the other learnt responses, namely symbolisms of the conscious, cultural influences and mannerisms, influence of trends, fashions, and styles. Personal relationship to colour which is connected with and influenced by all the other levels could be found at the top.

2.2 Use of Colour Associated Emotional and Behavioural Response to Support Human Activities in the Built Environment

The current study will focus on the innate or universally applicable emotional and behavioural response to colour which has the potential to support human performance in built environments. Researchers suggest that the quality of the environment has a direct impact on human behaviour. In conjunction with this belief, it has been suggested that the appropriate use of colour can enhance the overall quality of the environment and, thus, influence behaviour (Mahnke, 1981). Colour can act as a subtle environmental cue that has important influences on behaviour (Elliot at el 2007). Many prisons, hospitals, companies, and schools have adopted systematic colour schemes which have been designed to produce particular performance states in their inhabitants (Etnier and Hardy 1997). The colour of the work environment may affect performance (Kwallek & Lewis, 1990). Few examples for the usage of functional value of colour to support a particular human behaviour are as follows.

The arousing effect of colour red has many usages. Red is used to increase appetite and table turnover in restaurants (Gruson 1982). A vey recent study done by Zhu (2009) revealed that colour red can make people's work more accurate cautious and detail-oriented. It helps in enhancing memory (Belluck 2009). Red light has been found to increase strength by 13.5% and is used to increase athletic performance for athletes who need short, quick bursts of energy (Dagget, Cobble and Gertel 2008).

The sedating effect of blue has been used logically to support human performance. Students' blood pressure dropped and their behaviour and learning comprehension soared when architects changed schoolroom walls from orange and white to blue (Barrett 2007). Blue streetlights are found to be useful in preventing suicides and street crime (Shimbun 2008). On the other hand as revealed by Zhu (2009 cited in Belluck 2009) blue can be integrated in the spaces where a person needs to be more creative. Blue light assists in performances of athletes who require a steadier energy output. (Azeemi & Raza 2005)

According to research, pink has a tranquilizing and calming effect within minutes of exposure. It is capable of suppressing hostile, aggressive and anxious behaviour. Pink is also reported to reduce muscle strength in inmates. Pink holding cells are now widely used to reduce violent and aggressive behaviour among prisoners (Azeemi & Raza 2005). At a county jail in Texas inmates are dressed in pink jumpsuits. They sleep on pink sheets and wear pink slippers. Even the walls and the bars of the cells are painted pink (Glaister 2006).Several municipalities are experimenting with passive pink to stop graffiti, while football coaches try the colour in visitors' dressing rooms, to debilitate their opponents(Gruson 1982).

Use of colour in hospital design to support function plays a vital role in terms of patient recovery rates and improving the quality and overall experience of patients (Dalke et al. 2005). The integration of supportive colours in hospital environment may vary as per the illness of the patient. For instance brighter colours may be preferred for patients with depression and some older adults, but they could be over stimulating for highly agitated patients. (Karlin & Zeiss 2006).

On the other hand, several researchers reveal the adverse effects of colours on certain human performances, which is another important facet of this association needs to be considered. Stone (2001) found that, reading comprehension decreased in a red room, which is socially considered to be a warm colour. Red seems to impair performance on achievement tasks, due to its association with the danger of failure in achievement contexts and evokes avoidance motivation. The findings suggest that care must be taken in how red is used in achievement contexts (Elliot at el 2007). Gimbel suggests a possible relationship between violent street crime and sodium yellow street lighting. (Gimbel as cited in Azeemi,S.T.Y & Raza,S.M 2005).

The complete characteristics of the innate, intrinsic or fixed biological responses to colour stimuli is yet to be discovered. However, colour associated fixed emotional and behavioural responses, could be manipulated logically to support human activities/performance in built spaces. Out of aforementioned responses, the present study will predominantly limit its scope to a single aspect of colour which emerges as part of the whole process of intrinsic response; colour associated thermal perception of human beings. To explain precisely, the study will investigate the potential of integrating colour to enhance the thermal environment demanded by diverse human functions. This association is identified as an underutilised aspect of the functional value of colour.

2.3 Research Focus - Colour and Thermal Perception of human beings

Colour is said to have a relationship with human's thermal perception. In other words, colours can be described in temperature terms (Ballast, 2002). Accordingly certain colours, namely reds, yellows and oranges, are perceived by humans as warm. While blue, green, purple hues are perceived as cool. Yet the scientific investigations done on the nature and potentials of this association is scarce. At this juncture, the current research seeks in fulfilling three main objectives.

1) Providing evidence for colour associated thermal perception using scientific methods.
2) Distinguishing colour as a parameter pertaining to human thermal environment.
3) Establishing a correlation between colour, thermal perception and human functions preferred.

Theory of colour distinguishes a relationship between colour and perceived temperature, thus differentiating between "warm colours" and "cool colours". According to Ballast's (2002) explanation colours can be perceived as "warm" or "cool" related to the dominant wavelength of the colour (Ballast 2002 cited in Daggett, et al , 2008).

Similar to the other entire colour associated emotional/behavioural responses; thermal perception relevant to a particular colour too can be a highly subjective response which differs from person to person. Yet, there are certain common connotations emerging as a consequence of fixed intrinsic, biological or inherited and primordial responses that emerge through the collective unconscious, which is the focus of the present study. On the other hand there can be exceptional situations where these inherited and primordial colour associations may be overridden by personal unconscious reactions that are learnt through the influence of an individual's personal experiences. For instance blue is identified to be perceived as cool. Yet contradicting all research on colour symbolism and psychological effect, a person may associate an ice-blue tone with heat, because as a toddler he burned himself on an object of that colour (Mahnke 1996).
In fulfilling the main objectives, the study has formulated three hypothetical sub questions and looked for evidence from existing literature.

3.0 Hypothetical Sub Questions

3.1 HSQ 01 - Colour Vs. Thermal Perception

Can colour alter human thermal perception regardless of ambient temperature?

Theorists suggest that perception of colours as warm and cool could possess primordial learnt connotations. Warm colours are suggested to associate with the warmth of fire and sun while cool colours are believed to connect with the coolness of the sea, sky, and foliage. As described by Belvalkar (2012), perception of red, orange, yellow and different tints and shades of them as warm could be a depiction of fire, which is characterised by all these colours. The prime purpose of fire discovered by the prehistoric man was warmth and light. Since then, man has associated fire with warmth, and thus all the colours of fire are warm colours. On the other hand, water and trees always made the atmosphere cooler and calmer; hence blue, green, violet and all the tints and shades of these colours came to be the cool colours (Belvalkar 2012).

Supposedly, as a consequence of intrinsic biological reactions triggered by colour stimuli, warm colours are said to stimulate, arouse and activate human metabolism resulting in increased heart rate, blood pressure and body temperature, while cool colours work in the opposite end to appease and pacify. Validating the above ideology Schaie and Heiss (1964) explain that the high wavelength colours; red, orange and yellow, possess strong excitation potential and high arousal qualities, and they induce elated mood states. Further establishing the correlation between wavelength and felt arousal Plack & Shick, (1974),Wineman (1979), Walters et al (1982), Whitfield &Wiltshire (1990), Stone (2001) and Ballast (2002) claims that long waves (e.g. red, orange, yellow) are arousing and stimulating. Although there is no scientific proof so far, Cornelissen and Knoop (2012) suggest that red can make body temperature rise, thus people experience a feeling of warmth. Therefore the study postulates that high wavelength colours are perceived to be warm as a consequence of the innately fixed arousing effect on humans resulting in an increased body temperature. Thus high wave length colours are distinguished as "warm" colours.

The low wavelength colours, such as green and blue, are associated with more sedate mood states. These colours have relatively low arousal value and limited excitation potential (Schaie and Heiss 1964). The cool colours are generally considered to be restful and quiet (Ballast, 2002). Plack & Shick, (1974),Wineman (1979), Walters et al (1982), Whitfield &Wiltshire (1990), Stone (2001) and Ballast (2002) state that short waves are relaxing. The cool colours have many redeeming properties. They generally soothe relax, and induce leisure and contemplation. They are thought to be calm, secure, peaceful, and restful (Sharpe 1974 as cited in Bellizzi, Crowley and Hasty 1983). In another study conducted by Stone (2001) it was found that the arousal decreased in a blue room.

According to Kopacz(2003) the sight of the colour blue causes the body to release tranquilising hormones. Further he suggests that blue can lower blood pressure, slow the p ulse rate and decrease body temperature. Even though no scientific proof is evident in literature, the theory of chromo therapy explains a relationship between colour and body temperature. Therefore it can be hypothesised that low wavelength colours are perceived to be cool as a consequence of the fixed sedating effect on humans, resulting in a decreased body temperature. Thus low wave length colours are distinguished as cool colours.

Owing to the fixed innate responses it can be theorised that each colour is capable of triggering a different arousal level characterised by a corresponding thermal condition within human beings, consequently effecting thermal perception as well. In other words colour of a room will have a direct effect on ones perception of room temperature. Thus each colour is capable of triggering a relevant thermal perception regardless of the ambient temperature.

Only a handful of researchers have been touched upon this paradigm of colour research and come up with supportive proof. Sundstrom (1987) suggests that the colour of surroundings might have a distinct impact on changing perceptions of room temperature. According to Morton (1995), tests document that people estimate the temperature of a room with cool colours, such as blues and greens, to be 6-10 degrees

Fahrenheit cooler than the actual temperature; warm colours, such as reds and oranges, will result in a 6-10 degrees Fahrenheit warmer estimate. Hutchison (2003) reports that in another study done with work groups, walls painted "cool blue" induced more women to complain of being cold with the temperature set at 75 degrees than when the colour was changed to warm yellows and restful greens at the same temperature. Stone (2001) found that individuals performing within blue partitions perceived the temperature to be cooler than those in the red partitioned workspaces. Plack & Shick found a significant increase in the complaints about the coldness in an office which was painted blue after being yellow even though the actual temperature in the office had not changed (Plack & Shick, 1974). According to the very few supportive findings it can be suggested that colour is capable of altering human thermal perception regardless of ambient temperature.

3.2 HSQ 02 - Colour Vs. Human Activity

Can colours trigger corresponding arousal levels that will consequently support human activity and behaviour?

Every human activity is supposed to demand a unique state of existence for its optimum performance. Existence of human beings generally will fall in to three basic states; stimulated state, pacified state or a neutral state. For instance, humans are very active when they perform activities like dining, shopping, playing and conversing. On the other hand they will be pacified and concentrated when reading, studying and meditating. They will be at a neutral stance when they are relaxing. Human performance within any built space created may fall within any of such category. Shopping malls, dining spaces, gyms, and bars are designed for humans to perform actively while libraries, exam halls, meditation areas demand the user to behave in a pacified and more concentrated pace.

Therefore, designing spaces to facilitate the intended pace of existence; stimulated, pacified or neutral is vital. In doing so, colour can be an effective tool to support the demanded pace of existence or the level of arousal. As mentioned previously, each colour is capable of triggering corresponding arousal levels that will consequently affect human activity and behaviour. Birren (1989) states that warm colours are related to an active behaviour, while cold colours resemble a rather passive behaviour. Affirming this line of thinking, Gerard (1958) as cited in Graham 2000) suggests that psycho-physiological activation increases with the wavelength from blue to red. Therefore the study suggests that warm colours can be integrated to enhance active simulative spaces while cool colours will work well in pacifying spaces.

3.3 HSQ 03 - Association between Colour, Thermal Perception and Human Activity

Can colours trigger corresponding arousal levels that will set the thermal environment to support human activity and behaviour?

The current study is attempting to establish a correlation between three variables, namely colour stimuli, thermal perception and human performance/functions. Even though research conducted thus far do not directly support the above correlation, certain researches done on human responses to temperature conditions have found through the analysis of literature, to trigger parallel effects as colour stimuli.
For a case in point, as reported by (Schoer and Saffron 1973; Fisher 2001) temperature in classrooms affect

schoolchildren's performance. Going into details, Holmberg and Wyon (1969) revealed that student's behaviour was significantly affected by raised classroom temperature; girls became restless while boys began to behave in an undisciplined way and were observed to concentrate less. It was reported that reading comprehension and reading speed were reduced by raised temperature conditions. As per Stone (2001) reading task was lowered in a red environment. Thus both the red environment and raised temperature has affected human behaviour in the same manner suggesting a relationship between colour red and high temperature.

According to the principle of colour therapy, using more of blue colour in the bed room will help insomnia or sleeplessness (Hari 2003). Equally, the right room temperature can play a crucial role for a good night rest. Studies have found that the optimal temperature for sleep is quite cool, around 60 to 68 degrees Fahrenheit. For some, temperatures that fall too far below or above this range can lead to restlessness. A growing number of studies are finding that temperature regulation plays a role in many cases of chronic insomnia (O'connor 2009). Consequently blue colour can be identified to have a correlation with a cool thermal condition as both conditions are found to help insomnia.

Thus logically, there is a clear association between colours, thermal perception and human activities.

4.0 Contributions

4.1 To Create the Thermal Environment Demanded by Human Functions

With the logical and meaningful integration of the above association, colours can be potentially used to create the demanding thermal environment desirable for the function/activity intended in a built space. For instance, as revealed through the above analysis, cool thermal perception of colour blue in a bed room can support insomnia as the thermal environment demanded for sound sleep is quite cool.

4.2 Colour as an energy conservation tool

This association has a greater importance in energy conservation as well. For instance the energy spent on heating or cooling can be cut off to a certain extent by integrating the relevant colours at the right place; cool colours in a west facing room, warm colours in cold climatic regions of the world.

5.0 Research Design

The current research looks in to thermal perception associated with several selected colours namely; white, blue, red, yellow, purple, green and orange while seeking potential human activities which could be supported by the same colours. Eventually, the current study attempts to synthesise the findings associated with the same colour to establish a relationship between colour, thermal perception and human activity preferred.

5.1 Factors Determining Human Thermal Perception.

In formulating the research design the study probes into the already established factors pertaining to human thermal environment which consequently affect thermal perception. The Oxford Dictionary defines perception as the ability to see, hear, or become aware of something through the senses. It is further clarified in psychological & zoological terms, as the neurophysiologic processes, including memory, by which an organism becomes aware of and interprets external stimuli. Heat energy is recognised to trigger human thermal perception. Therefore thermal perception in general terms is the process of becoming aware of and interpreting the external heat stimuli and become aware of warmness or coolness through human senses; generally the skin.

The physics of heat transfer is straightforward, involving only three primary processes; conduction, radiation, and evaporation, and one auxiliary process, convection (Blumberg 2002, p 20). The combined effect of the aforementioned mechanisms of heat transfer to a greater extent will create the human thermal environment at any given time. Body temperature rises and a person feels warm if the heat generated inside the body is more than the heat lost to the environment. Similarly, body temperature drops and a person feels cool if the heat generation is less than the heat loss (Houdas and Ring, 1982)

Human thermal environment: Human thermal environment as a whole is a combination of several external and personal parameters. In order to comprehend on the aforementioned parameters this study will refer into the well established variables which determine the perception of thermal comfort. To define in general terms, thermal comfort or thermal neutrality is the state that an individual prefers neither a warmer nor cooler conditions, and that conditions are comfortable for the majority of people in any particular group (Wilson and Belshe 2001). Thermal comfort as defined by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) is defined as the condition of mind which expresses satisfaction with the thermal environment. As defined by Gagge et al. (1967) it is the conscious appreciation of warmth or cold and is an interpretation of thermal information from the skin and the inner body.

Accordingly, the current study logically argues that thermal comfort or discomfort is a decision which is arrived at as a consequence of human thermal perception. To clarify further, once a person is triggered by external heat stimuli through his senses, a neurophysiologic process will be activated and that information will be interpreted and analysed in his mind with the use of stored memory to arrive at the decision whether he/she is feeling too hot or too cold.

Parsons (2003) argued that thermal sensation is both a sensory and a psychological phenomenon. Since sensation is about how people feel, it is not possible to define it in physical and physiological terms. Thus, perception is always a subjective process moulded with past experiences and memories of each individual. Therefore it seems that humans perceive or respond to the thermal experiences in an altered manner (Ogoli 2007). Thermal comfort is essentially an emotional response contrary to the thermal sensation which is a rational response (Tanabe and Kimura, 1994). Thus the study stresses that the variables of thermal perception are same as thermal comfort variables.

5.2 External Parameters of Thermal Perception

A range of environmental and personal factors will work together contributing to this decision which is distinguished as the 'Human Thermal Environment'. Thermal comfort is based on the heat balance between the human body and the environment and is regulated through four environmental and two personal parameters (Zhang et al., 2004). As explained by Parsons (1993), air temperature, radiant temperature, humidity and air movement are the four basic environmental parameters. Combined with the personal parameters of metabolic heat generated by human activity and clothing worn by a person, they provide the six fundamental factors which define human thermal environment. The general, but fundamental, point is that it is the interaction of the six factors to which humans respond (Fanger 1970, Parsons 1993).

The above parameters are mainly identified based on the means of heat gain and heat loss from a human body. There is a continuous heat exchange between the human body and the thermal environment. For a human being to be thermally comfortable a perfect balance between heat gain from the environment and loss from the body should be achieved. The four external parameters are as follows.

a) Air temperature:
The temperature of the air surrounding the body can be distinguished as a principle factor of thermal perception. As a major component in convective heat transfer, air temperature moderates surface temperatures. These in turn further influence sensed temperature and comfort (Wilson and Belshe 2001).

b) Radiant temperature:
If there are heat sources in the environment radiant heat may be present which has a greater influence than air temperature on how humans lose or gain heat to the environment. The human body is constantly radiating energy to the environment while absorbing radiant energy from heat sources around. Depending on the relative temperature of the surfaces surrounding an occupied space, personal comfort can be greatly enhanced or compromised (Wilson and Belshe 2001).

c) Air velocity:
The air velocity or moving air will provide a cooling or heating effect on human beings (Wilson and Belshe 2001).

d) Humidity:
The impact of humidity levels is another external factor pertaining to thermal perception. At air temperatures above 75°F, the body begins perspiring. If the surrounding relative humidity is low enough, a significant amount of this perspiration undergoes a change of state and evaporates as water vapour. For each pound of water evaporated, the latent heat of vaporization extracts 970 Btu of heat from our bodies, thus providing significant cooling. Similar to cooling by perspiration—heat dissipation by respiration or panting is both a convective heat transfer mechanism as well as a form of evaporative cooling (Wilson and Belshe 2001).

Accordingly, a change in any of the above external parameters will cause a change in human thermal perception.

5.3 Human Parameters /Internal Parameters Pertaining to Thermal Perception

Two main parameters have been identified as related to the occupants' namely metabolic heat production and clothing insulation Fanger (1970), Parsons (1993), Matjaz (2006). Yet analysing the human factors in depth Wilson and Belshe (2001) add four more parameters namely, natural body responses, activity level, reactions to CO and other chemicals and conduction from body.

e) Metabolic Heat Production
Metabolic heat generation is supposed to be the most essential personal variable of the perception of thermal comfort.
Maintaining the core body temperature in the normal range (37ºC +/- 1ºC) is vital for its optimum performance and metabolic heat production plays a major role in this regard. The metabolic heat generated by oxidation of food in the visceral organs and tissues (body core) is a constant source of heat (King, 2004). This food-to-heat conversion process is called metabolism (Wilson and Belshe 2001).Metabolic heat production is a dynamic phenomenon which varies due to diverse factors namely; age, body

temperature, gender, sleep cycle, height, weight and skin surface area, pregnancy, menstruation, lactation, growth, prolonged fasting, infection and other diseases, recent ingestion of food, muscular activity, emotional state, ambient temperature, hormones and other conditions (Vander, Sherman and Luciano 1980 as cited in Wilson and Belshe 2001). Increased metabolic activity will enable a person to perceive an elevated thermal level.

f) Clothing Insulation

According to laboratory studies, a naked person sitting quietly is comfortable at 82.4°F (Fanger, 1970). Clothing insulates the human body from losing heat to the environment. People in all parts of the world existing in widely variable climates have evolved a plethora of clothing styles appropriate for local climate needs to protect themselves from both heat and cold and controlling moisture movement (Wilson and Belshe 2001).

g) Natural Body Responses

As explained by Wilson and Belshe (2001), warm-blooded creatures including human beings are able to adapt and live in a wide range of environments via a complex system by which they generate their own heat and regulate the internal temperatures. This process of controlling body temperature is identified as thermoregulation. Body temperature is kept constant by balancing both heat gain and heat loss. Humans need to maintain a constant body temperature of about 37°C. To maintain this temperature at a constant point throughout the body's internal systems, mechanisms must be in place to accurately measure present body temperature, and to regulate as needed. This system is known as the thermoregulatory system (King , 2004).

Hypothalamus is the basic body controller for thermal comfort. Being a gland at the base of the brain it is essentially a thermostat set at 98.6°F. When it senses that the body is losing heat faster than it is generating it, it secretes hormones and sends nerve impulses to various parts of the body to increase the metabolic rate, constrict blood vessels and other changes. Under over-heated situations, the hypothalamus sends out just the opposite signals. When certain pathogens or disease trigger the brain, many of these same temperance regulators are brought into play to raise the core body temperature to help fight off these viral and bacterial invaders (Wilson and Belshe 2001).

h) Activity Level

The body generates heat at widely varying levels depending on activity: Therefore the activity in which a person is involved will also contribute in determining thermal perception. Eagan as cited in Wilson and Belshe (2001) identifies the relationship between activity and heat generation.

i) Conduction from Body

Conduction of body heat through direct contact with cold surfaces is a far more efficient mode of heat transfer than convective losses to the air. Bare feet on cold floors are clearly more of a source of local discomfort than bare hands in air of the same temperature. Direct contact with cold surfaces allows these heat sinks to draw out body heat (Wilson and Belshe 2001).

j) CO and Other Chemical Reactions

Human bodies are indeed very complex systems with chemical stimuli and responses affecting all biological and physical activities. Besides the known health effects of even low levels of CO, this toxin also influences our perceptions of thermal comfort. Under conditions of reduced oxygen levels and increased levels of carbon monoxide or carbon dioxide, the heart is induced to increase the blood flow in order to try to deliver sufficient oxygen to body tissues. With increased blood flow, there can be a false sense of warmth and comfort with a feeling of well-being and lethargy (Wilson and Belshe 2001).

To recap, there are four external variables pertaining to human thermal environment namely air temperature, radiant temperature, humidity and air movement. Further there are several human or internal parameters which contribute to the perception of thermal environment. They are metabolic heat production, clothing insulation, natural body responses, activity level, reactions to CO and other chemicals and conduction from Body.

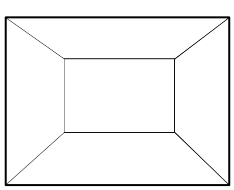
The present study argues that the factors contributing to thermal perception of humans or thermal environment transcend beyond these well established parameters. Significantly thermal perception can be beyond tactile sense. Thermal perceptions are affected by factors that are not recognized by current comfort standards. The factors include thermal history, non-thermal stimuli and psychological expectations (Humphreys, 1996; Karyono, 2000). The current study inquires the potential of colour to be considered as another parameter determining human thermal environment. Similar to seeing colour in music identified as sound, colour synesthesia (Cytowic & Eagleman 2009), thermal, colour synesthesia; perceiving temperature through colours could be possible. Colours can potentially be non-thermal stimuli which have an effect on human's thermal perception. Therefore the study will attempt to investigate the effect on colour on thermal perception. In doing so, the aforementioned external and personal parameters have to be controlled.

6.0 Survey Instrument

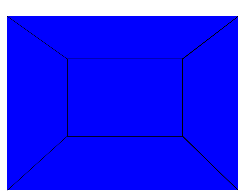
This preliminary investigation was conducted with a group of normal sighted, healthy volunteer undergraduates (n=72, 51 females and 21 males) of University of Moratuwa. The participant's belonged to an identical age group (ranged between 20-23 years) and represented a cross section of the socio cultural religious and topographic contexts in Sri Lanka. It was attempted to control the external parameters which directly effect on thermal perception via conducting the study within an air conditioned controlled studio environment with a fixed lighting level. Controlling the personal factors were not possible due to practical reasons, especially clothing insulation, since it is a preliminary investigation conducted with volunteer undergraduates. Any how the participants' pace of existence and the activity level were essentially the same as they were comfortably seated in the studio while involved in the given tasks. The study was focused on two main parts.

Part one:

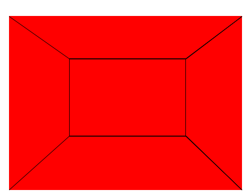
The participants were shown computer generated slides of an identical room in seven different colours (as specified in RGB colour model) projected on to a wall ;namely Red(255,0,0), orange (255,165,0), yellow (255,255,0), blue (0,0,255), green (0,128,0), purple (128,0,128), White (255,255,255). In other words each slide demonstrated an identical room in a particular colour as shown below.



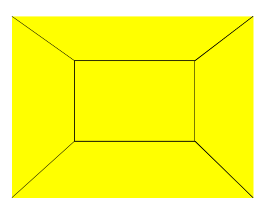
1) White - RGB 255,255,255



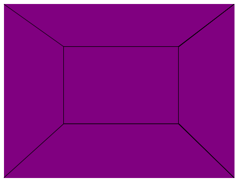
2) Blue – RGB 0, 0,255



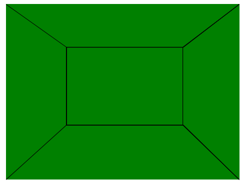
3) Red – RGB 255, 0, 0



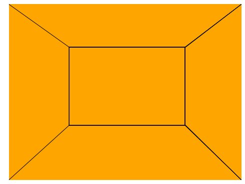
4) Yellow RGB - 255, 255, 0



5) Purple - RGB 128, 0,128



6) Green – RGB 0, 128, 0



7) Orange – RGB 255, 165, 0

The room temperature was maintained at a constant level (26^{o}C). The participants were shown each slide for two minutes and they were requested to rate their TP (warmness/ coolness) per each room on a 5 -point likert scale (Very Cool, Cool, Average, Hot, Very Hot).

Part two:

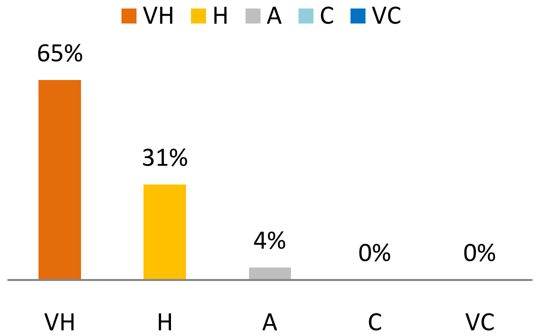
Part two attempted to identify activities they preferred to perform within each of the above projected rooms. Using the guided imagination technique, the participants were guided to imagine as if they are experiencing the above coloured rooms as real and select (√) the activities they would prefer to perform in each room out of a list of activities given to them namely, sleeping, exercising, dining, reading, solving mathematical problems, having discussions with friends, meditation, sports, relaxing and drawing a picture. They were allowed to select the same activity for more than one colour if necessary.

Imagination is one's innate ability to form mental images. It was considered that responding to visual slides with the use of participant's spontaneous imagination is equal to the effects of being in the rooms. The imagination produces strong feelings in most of us as just as fiction does. Findings from brain imagining indicate that the same rejoins of the brain are used in very similar patterns, whether one visually experiences a given object or one imagines such an object (Kandel, Schwartz and Jessell 2000, Kosslyn 1994 as cited in Nichols 2006). As stated by Kein (1985), the brain and nervous system respond only to mental images. It does not matter if the image is self-induced or from the external world. To clarify in detail, once light reflected from an external object hits a perceiver's eyes an electrochemical change will occur producing nerve impulses that are transmitted to the visual centre of the brain where the information is interpreted in the form of visual images. Consequently it can have the same emotional effect be it real or imagined information. Supporting this line of thinking (Mahnke (1996 p. 7) establishes that, colour is not dependent only on the external world but may also originate through the power of imagination of our inner world. Based on supportive literature the responses made to an imagined coloured room were considered as equal to the real experience of the same in the current investigation.

7. Data collection

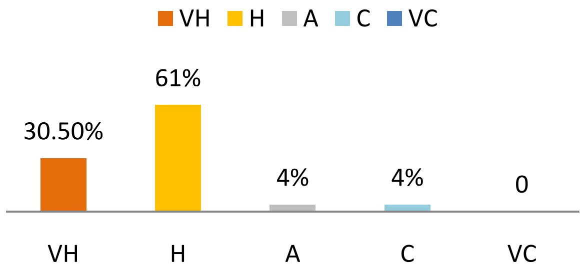
The data was collected and analysed with the use of excel sheets and the findings are represented via bar charts and line charts as illustrated below.

7.1 Data Series 1 - Rated thermal perception per colour



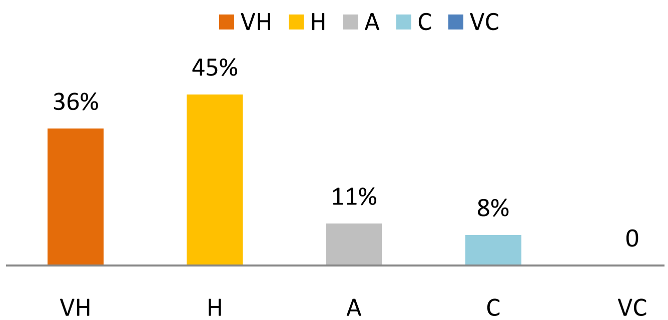
Red was significantly perceived to be very hot (65%). None perceived red as a cool colour.

Graph 1 – Thermal Perception Associated with Red.



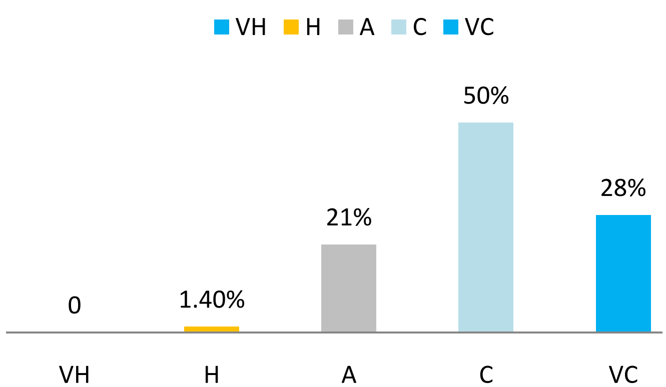
Majority (61%) perceived orange as a hot colour. None considered orange to be a very cool colour.

Graph 2 - Thermal Perception Associated with Orange



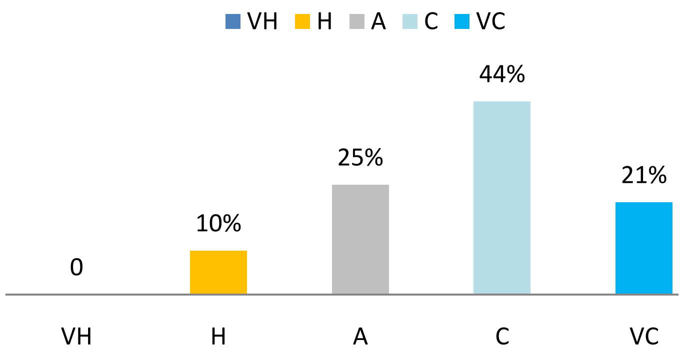
Yellow was mostly (45%) perceived as hot while another 36% perceived it as a very hot colour.

Graph 3 - Thermal Perception Associated with Yellow



Green was significantly perceived to be a cool colour (50%). Green was not considered to be a warm colour.

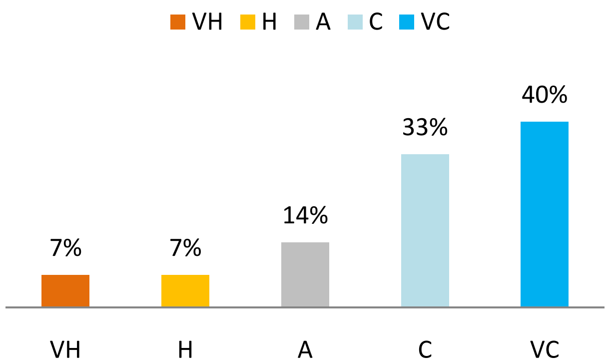
Graph 4 - Thermal Perception Associated with Green



Most responses on purple were to say it was a cool colour. (44%)

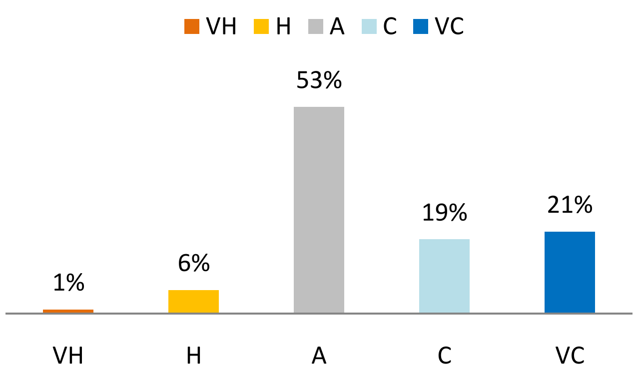
None considered it to be a very hot colour.

Graph 5 - Thermal Perception Associated with Purple



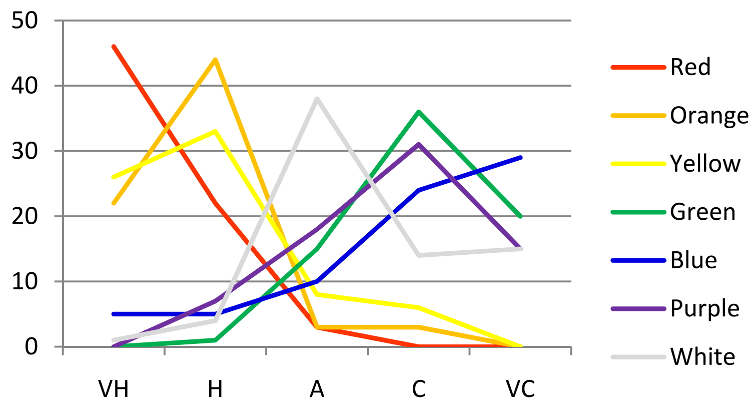
Blue received the highest number of responses as the coolest colour (40%) above all the colours tested.

Graph 6 - Thermal Perception Associated with Blue.



White was identified by a majority to be an average colour; neither hot nor cool (53%).

Graph 7 - Thermal Perception Associated with White

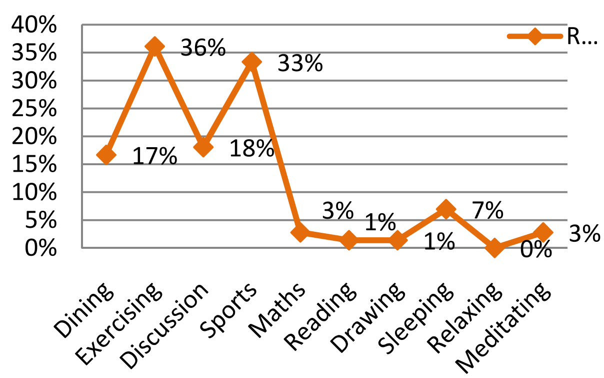


Red – Very Hot
Orange – Hot
Yellow – Hot
White – Average
Purple – Cool
Green – Cool
Blue – Very cool

Graph 8 – Overall Thermal Perception for the given colours

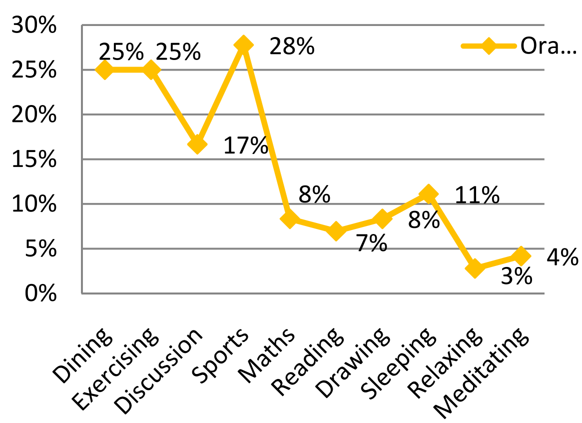
7.2 Data Series 2 - Activities Vs colour

Referring to the graphs representing colour vs. activity preference, activities chosen at the peak level was considered to be mostly favoured per each colour.



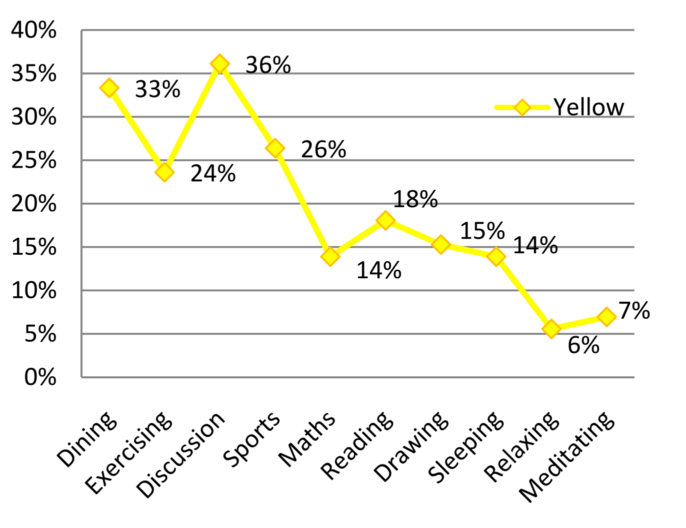
Sports and exercising were dominating at the peak level of the graph as activities preferred to be performed in a red room. Significantly calm and concentrated activities were firmly not preferred in a red room; relaxing, reading, drawing and meditating.

Graph 9 – Activities preferred in **red room.**



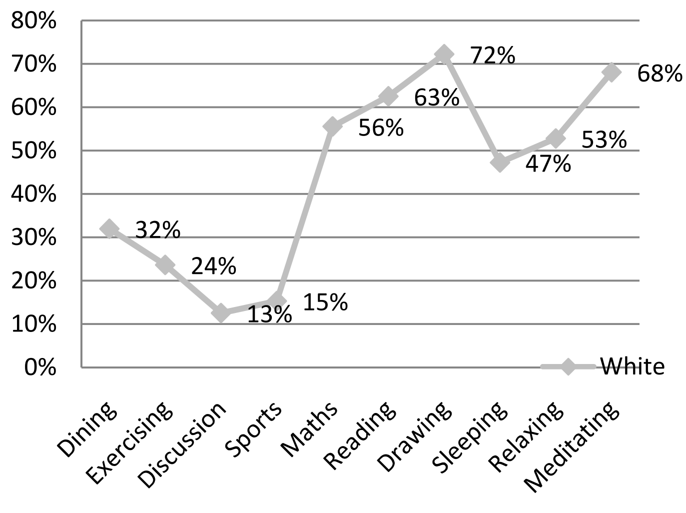
Functions performed in an active pace of existence namely sports, exercising and dining were significantly preferred at peak level in an orange room. Similar to red, calm and concentrated activities were more or less not preferred in an orange room; relaxing, meditation.

Graph10 – Activities preferred in **orange room**



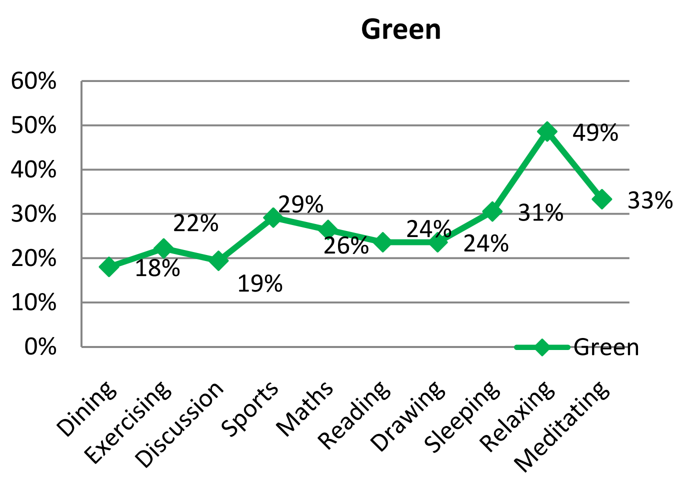
Graph 11 – Activities preferred in **yellow room**

The graph has moved upwards demonstrating a variety of activities which can be performed in a yellow room. Yet active functions namely, discussions dining and sports and exercising had the higher preference at peak level. The participants moderately preferred to read, draw and solving maths problems in a yellow room. Yellow was barely preferred for calm/neutral activities namely, meditation and relaxation



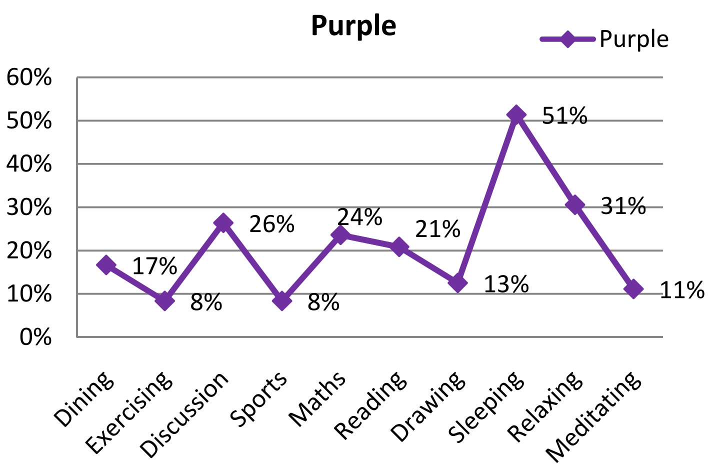
Graph 12 – Activities preferred in **white room.**

White was highly preferred for functions to be performed in a calm appeased state and neutral state of existence than activities of high arousal; drawing, meditations and reading. On the other hand it was not much preferred for active performances like exercising, discussions and sports.



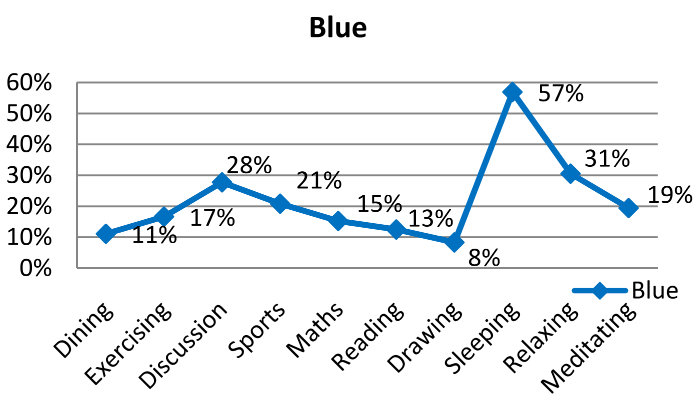
Graph 13 – Activities preferred in **green room**

Green demonstrates a large scope in terms of activities in both active and calm range. But it was highly preferred for relaxing.



As depicted by the graph, purple was preferred by a majority for sleeping. Demonstrates a large scope in termas of activities in both active and calm range.

Graph 14– Activities preferred in **purple room.**



Blue was dominantly preferred for sleeping and moderately for relaxing.

Graph 15– Activities preferred in **blue room.**

8.0 Analysis

Findings of this study provide testimony for colours' ability to alter human's thermal perception. Each colour significantly was found to be associated with a certain thermal perception.

Red was significantly perceived to be very hot (65% -VH, 31-% H, 4%-A, 0%-C, 0%-VC). Accordingly, 96% rated red to be warm. None perceived red as a cool colour (0%). Majority perceived orange as a hot colour (30.5-% VH, 61%- H, 4%-A, 4%-C.0%-VC) and none considered it to be a very cool colour (0%). Orange was another colour significantly perceived as warm (91.5%). Yellow too was mostly perceived to be a hot colour (36% - VH, 45% - H, 11% -A, 8% -C, 0% - VC). 81% rated yellow to be another warm colour. Accordingly, supporting the theory of colour, red, orange and yellow were perceived significantly as warm.

Green was significantly perceived to be a cool colour and was not considered to be a warm colour (0%-VH, 1.4% -H. 21% -A, 50% -C, 28%- VC). Majority perceived purple to be a cool colour (0%-VH, 10% -H. 25% -A, 44% -C, 21%- VC). None considered Green and purple to be very hot colours.

Above green and purple, blue was identified to be the coolest colour (7%-VH, 7% -H, 14% -A, 33% -C, 40%-VC). Thus affirming the colour theory, green, purple and blue were dominantly perceived as cool. Only a very few respondents rated these colours as warm. On the other hand a minor tendency to perceive green (21%), purple (25%) and blue (14%) to have an average a TP was evident in the findings, unlike warm colours.

Aligned with theory of colour, white was identified by a majority to be a neutral colour; triggering neither a hot nor cool perception (1%-VH, 6% -H, 53% -A, 19% -C, 21%- VC). Even though only a handful of respondents rated white as warm (7%), it was considerably marked as a cool colour (C+VC=40%). Recognizing white as a cooling colour could be a learnt association strongly moulded by the Sinhalese, Buddhist religious context.

Red was found to be the colour perceived as the warmest out of all colours tested while blue was found to be the coolest. Accordingly the following relationship between TP of seven colours tested was arrived at; TP Red > TP Orange > TP Yellow > TP White > TP Purple > TP Green > TP Blue.

Referring to the graphs representing colour vs. activity preference, activities chosen at the peak level were considered to be mostly favoured for each colour. Supporting the hypotheses, the participants preferred to perform active functions in the rooms which they rated to have a high TP and vice versa. For instance, red room was preferred for exercising and sports while orange were preferred for sports, dining and exercising. Further, yellow was marked as suitable to have in a space for friendly discussions, dining and sports. The colours identified to have a low TP were significantly preferred for calm activities. Blue and purple respectively were decidedly preferred for sleeping and relaxing. Green room was dominantly preferred for relaxing. White, which was mostly rated to have an average TP was chosen for calm and neutral activities mainly, drawing, reading and meditation.

On the other hand colour and thermal environment were found to have parallel effects on human performance. For instance blue was found to associate with a very cool thermal condition and was found to support sleeping while red was found to be perceived as very hot and correlated with active performances like exercising and sports.

9.0 Conclusions

The current study supports the theory that each and every colour is associated with a particular perceived temperature. TP of red, orange and yellow coloured slides were rated as warm and blue, green, purple slides were rated as cool while white room was rated to have an average TP. Red was found to have the highest TP and blue was found to trigger the lowest TP.

On the other hand, supporting the hypothesis, the study reveals a relationship between colour stimuli, thermal perception and preferred human activities. As mentioned above the responses to an imagined coloured room were considered as equal to the real experience of the same room in the current study. Human functions performed in aroused, active pace were preferred to be carried out in spaces with warm colours while calm and concentrated activities were preferred for spaces with cool colours. Since rating the thermal perception and the identification of preferred activities related to each colour were done simultaneously a relationship between thermal perception and activity was also established as given below.

Colour	Thermal Perception	Activity Preferred to be performed
Red	Very Hot	Exercising, sports
Orange	Hot	Sports, exercising, dining,
Yellow	Hot	Dining, discussion
White	Average	Reading, drawing, meditation
Green	Cool	Relaxing, meditation
Purple	Cool	Sleeping
Blue	Very cool	Sleeping, relaxing

Table 2: Conclusion - Colour, Thermal Perception Vs Activity Table

The study investigated a particular functional value of colour, to enhance the thermal environment with the use of colour stimuli to support human performance in the built environment. The study established that activities like sports, exercising, dining, and discussion were preferred in a warm thermal environment and thus warm colours can be integrated to enhance such performances; Red and orange colours for sport and exercising , yellow for spaces where dining and warm discussions take place. In the other end the study claims that cool colours can be integrated in spaces for sleeping, relaxation and meditation. In conclusion colour is identified as a parameter pertaining to human's thermal environment. It is suggested to extend this investigation more precisely via controlling the personal variables (clothing insulation), considering different age groups, situational groups and increasing the sample size.

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