Colour associated thermal perception (CTP): Evidence from an experimental research design implemented in Sri Lanka.

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Abstract

Colours have been hypothetically recognized to alter perceived temperature and thus differentiated as warm colours and cool colours, even though not satisfactorily supported via scientific inquiry. Given that this association could be generalized, the current investigation proposes its integration to create the optimal perceived thermal milieu demanded by human activities in built environment eventually working as a potential hybrid approach for energy conservation. In order to comprehend the logic behind warm-cool dichotomy of colour perception and to provide scientific explanation on its nature, emergence and significant factors, an experimental research design was adopted with reference to red and blue associated thermal perception (RTP and BTP).

It was affirmed that a warm RTP and a cool BTP can be generalized. Colour blind subjects were found to perceive the same suggesting possibilities of CTP beyond visual perception. Colour associated thermal perception was found to be more of a psychological response. One's psychological state triggered by colour stimuli, preference to exposed coloured environment and the preconceived, learnt ideologies molded by educational background were found to have a significant impact on both RTP and BTP. Further, BTP was found to have relationship with subject's age, and the surface temperature of blue work station while subjects' favorite colour was significant for RTP. Accordingly, CTP was found to emerge as a subtle, complex combination of several layers; psychological, learnt, external as well as certain un-revealed factors.

Keywords: *Warm colours, Cool colours, Colour perception, Thermal perception, Colour associated thermal perception*

1) Introduction

The meaningful integration of colour to create optimum built spaces transcending its typical aesthetic and beautification value has been identified in the current study as a vital necessity in the contemporary field of architecture, landscape and interior design. Careful integration of the fixed psychophysiological effects of colour to manipulate human thoughts, feelings and behavioral responses in built environment to set the milieu demanded by the activities, have been increasingly attempted in this regard. For instance, use of red in restaurants to increase table turnover (Singh, 2006), pink in detention centers to suppress aggressive behavior of inmates (Schauss, 1981), blue street lights to prevent street crimes and suicides McClatchy (2008) and Shimbun (2008), are few such attempts. Colour is further distinguished for its ability to alter perceived dimensions and properties of space; height, width, depth, scale, proportion, weight, and temperature. A long – favored hypothesis maintains that colour has the power to suggest warmth or coolness (Mahnke &. Mahnke, R. H, 1996).This investigation is focused on the said unique ability of colours to alter human thermal perception (CTP).

Colours have been hypothetically recognized to alter human thermal perception. Theory of colour distinguishing this relationship, clearly differentiates between "warm colours"; red, yellow and orange and "cool colours"; blue, green, purple. This warm/cool dichotomy of CTP has been recognized by the author as a vital yet a barely utilized potential in designing built spaces. Lack of ample scientific evidence to comprehend on the nature, emergence and potentials of CTP has been identified as the main problem, which is the sole driving force of this investigation. Principally, it was attempted to obtain a comprehensive understanding on the logic behind CTP with reference to a warm colour (red) and a cool colour (blue) i.e RTP –Thermal Perception triggered by red colour and BTP – Thermal Perception triggered by blue colour.

The study further attempted in,

a. Providing scientific justification for dual nature of CTP; revealing the nature and emergence; whether it is a psychological response, a biological response, a response which transcend beyond visual perception (via examining colour blind subjects), a property of the colour (surface colour) which contributes to room temperature enabling a warm/cool TP, or a combination between several of or all these suppositions.

b. Identifying significant predictors contributing to CTP and their relationships.

Given that CTP could be generalized among all humans, it could contribute to architects, interior designers, landscape designers etc to integrate colour to aid the perceived optimal thermal ambience/milieu demanded by human activities in built environment. With further R&D, the above strategy has greater potential to be integrated as an effective hybrid method of energy conservation where colour becomes an energy conservation tool; application of warm colours in cool climatic region will contribute to energy conservation and vice versa. Accordingly colour will be a decisive factor that needs to be considered in developing effective energy saving applications in future.

2) Background

The basic theory under consideration is the principle of duality in human existence and the dual nature of human activities; stimulated vs pacified. Identifying a parallelism in dual impacts of colour on human existence based on wavelength and frequency as the basis for the theory of warm/cool distinction has been recognised; warm colours (high wave length colours) to have a stimulating, arousing effect and cool colours (low wave length colours) to have a pacifying, sedating, relaxing effect on humans (Plack & Shick, 1974,Wineman,1979, Walters et al 1982, Whitfield &Wiltshire,1990, Stone,2001 and Ballast ,2002).Accordingly, the study suggests a parallelism between duality of human activities and TCP and is supposed to be integrated effectively to support human activity in built environment via setting the corresponding arousal, emotional and thermal ambiences;

Warm colours: To create warm, simulative, energetic ambience facilitating active and energetic activities; e.g. - eating, playing, shopping, and exercising.

Cool colours: To create sedative, pacifying or contemplative ambience facilitating calm and concentrated activities; studying, reading, drawing, and contemplating.

CTP was considered as unification between two significant paradigms of perception; colour perception and thermal perception where two different processes are involved. As a main assumption, the parameters pertaining to human thermal comfort (Fanger, 1970, Wilson and Belshe, 2001) was considered as applicable to CTP as based on the logic that thermal comfort is an outcome of thermal perception. On the other hand factors contributing to colour perception was identified via a thorough literature review of which Mahnke's (1996) colour experience pyramid that explains the subtle psychological layers of colour perception was significant. The research was designed to control the predictors of thermal perception and colour perception supposedly pertaining to CTP as best as possible.

3) Hypothetical research questions

Principally it was hypothesized that CTP can be generalized among all humans. Accordingly it was assumed that RTP will be warm and BTP will be cool to a majority of the subjects.
Four hypothetical research sub questions were considered in exploring the nature of the CTP

a. **A fixed biological reaction?**

   It was assumed that an actual change in the body temperature is taking place enabling warm vs cool CTP. Temporal Artery Temperature (TAT) was considered to represent body temperature (Hebbar et al ,2005 , Lawson et al, 2007, Hegner, Acello and Caldwel, 2012).

b. **A Psychological reaction?**

   Possibility of CTP to be a subjective/learnt psychological reaction molded with socio, cultural, religious influences and mannerisms (Mahnke, 1996).

c. **A change in the external thermal environment?**

   Caused by colour leading to altered CTP due to properties of each colour applied ; colour reflective value, colour absorption coefficient will alter the applied surface temperature and consequently effecting CTP.

d. **CTP beyond vision?**

   Possibility of CTP to be a combination of both visual and skin perception, a union of two sensory pathways suggesting synesthesia; triggering one sensory path leading to the processing of another sensory organ; a cross link between the visual sense and the thermal sense (Mahnki, 1996) was considered via studying colour blind subjects in this regard.

4) Research Design

4.1) Output variable / Dependent Variable (DV) – RTP and BTP
Three identical workstations painted in White (WWS), Red (RWS) and Blue (BWS) were located in a controlled lab environment and the thermal perception in the RWS (RTP) and thermal perception in BWS (BTP) were tested while using the WWS as a control.

4.2) Predictors /Independent Variables (IVs)
The following tables summarise all the predictor variables suspected to have an impact on the DV based on literature, and how such variables were controlled during the experiment. Since the investigation is on colour associated thermal perception, predictors pertaining to both colour perception and thermal perception were considered.

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4.2.1) Participant IVs having an impact on Colour Perception

Variable	Controlling measures/ Data
Condition of eye sight	Couldn't control as participants were selected via simple random sampling. (Blind/colour blind subjects avoided). Vision was identified as a confounder (Normal vs Impaired) and included in the regression model.
Age	Included in the regression model in three categories.
Gender	Restricted only to a male sample to assure more accuracy in data.
Personal variations of perception molded by socio, cultural, religious, topographical, climatic and experiential constructs	Cannot be controlled- Included as a confounder. (Psy)
Sensitivity towards external stimuli ;warm /cool conditions (Dermal perception – Conditions of the skin)	Cannot be controlled- Included as a confounder. (Sen_cool ans Sen_warm)
Health condition (e.g. Increased blood sugar levels will decrease vision)	Controlled via a vigorous screening process; Medical checkup.
Colour preferences/ favorite or least favorite colours	Cannot control. Included in the model (Pre and FVC)

Table 1: Participant Variables of Colour perception

4.2.2) Control - Situational IVs having an impact on Colour Perception Properties of the applied colour in workstations

▪ **Colour reflectance value** (Could have a bearing on the thermal environment in WSs contributing to TP.)	Cannot fix as it is a property of colour- Differ from colour to colour (black 0% and white 100%) **(DATA –SFT)** Surface temperature readings to capture any possible change of WS temperature due to reflectance of colour radiation.
▪ **Colour absorption,** (Could have a bearing on the thermal environment in WSs contributing to TP.)	Cannot fix as it is a property of colour - Differs from colour to colour. **(DATA –SFT)** Surface temperature readings to capture any possible change of WS temperature due to absorption of colour.
▪ **Emissivity** (Could have a bearing on the thermal environment in WSs contributing to TP.)	Cannot fix as it is a property of colour - Differs from colour to colour. **(DATA –SFT)** Surface temperature readings to capture any possible change of WS temperature due to absorption of colour.
Area applied,	Controlled – Applied on the walls of WSs of identical dimensions in equal amounts.
Thickness of the paint coat,	Controlled – Applied 2 coats in all three WSs.
Finish (Texture; mat, gloss, semi gloss),	Controlled – Maintained the same matt finish.
Colour combination (Effects of single colour, two colours, three colours) ,	Controlled by applying a flat single colour.
Pattern	Controlled by applying a flat single colour.
Colour selection method. Additives colour method was used to generate colour. Criteria for colour selection was based on available theory; Red to be the warmest colour, blue to be the coolest colour representing the two opposite polarities of colour perception and response. White was selected to	Colour selection was done based on the **RGB colour model**; Require Pure Hue White - RGB 255,255,255 Blue – RGB 0, 0,255

represent the neutral state. Colour specification based on the **RGB colour model**; Also it was attempted to obtain the purest hue (Red – 255, 0, 0, Blue – 0, 0,255, White - 255,255,255) with the assistance of Causeway Paints. Due to the impossibility of mixing paint to create the exact RGB values, Causeway Paints research team at Holland head office was consulted for advice. The RGB values of closest purest hues to be mixed via the Colour box as specified by the specialists from Netherlands were as follows. (Jolanda de Jong, Technical Sales Tinting Systems, Ralston Colour & Coatings B.V. Russenweg 2-4, P.O. Box 205, NL-8000 AE Zwolle, The Netherlands) <u>White – 255,255,255</u> This is pure white: Base white with additional AQ40 colorant (for 1 litre base white, add 150 shot AQ40). <u>Blue – 0, 0,255</u> Most bright blue in colour fan is H03810, but RGB is 10, 111, 175 <u>Red – 255,0,0</u> Most bright red in colour fan is H00820, but RGB is 193, 57, 48	Red – RGB 255, 0, 0 The closest purest hue which could be obtained by Causeway paints are as follows. White - RGB 255,255,255 (1litre base white, add 150 shot AQ40). Blue – RGB 0, 0,255 Most bright blue in colour fan is H03810, but RGB is 10, 111, 175 Most bright red in colour fan is H00820, but RGB is 193, 57, 48 (Even though the above samples appear to be pale on computer screen the applied colours came very close to the proposed colours)
Lighting level	(The level of lighting received by each WS will have an impact on the dependant variable.) It was controlled by maintaining a uniform lux level (350 lux) in each workstation.
Time of exposure to coloured surface / environment	Was fixed to 15minutes in RWS and BWS and 10 minutes in WWs.

Table 2: Situational Variables of Colour perception

4.2.3) IVs having an impact on - Human Thermal Perception- Situational Variables

Being an empirical research, a thorough literature review was done and extensive discussions were taken with renowned medical practitioners and scholars. This helped in identifying and controlling the predominant factors (Internal and external or personal) pertaining to human thermal perception.

Considering the fact that thermal comfort is an outcome of thermal perception, already established factors pertaining to human thermal comfort were considered. (Fanger 1970, Parsons 1993, Wilson and Belshe 2001, Zhang et al., 2004).Further additions were done based on the review of literature.

Variable	Controlling measures
Air temperature	Controlled in a laboratory condition. Temperature was maintained at a constant level (26°C).
Radiant temperature	Controlled in a laboratory condition
Humidity	Controlled in a laboratory condition
Air movement	Controlled in a laboratory condition

Table 3: Situational Variables of Thermal perception

4.2.4) IVs having an impact on - Human Thermal perception- Participant Variables

Metabolic heat production Most essential personal variable of the perception of thermal comfort).	Cannot control as the subjects were selected via simple random sampling. BMI value was included as data in the regression model. (Asian average BMI= 19-23 Kg/m^2)
Clothing insulation	Controlled by making the subjects wear a fixed dress with o The same material - Cotton o Same colour - Black o Same body coverage
Natural body responses- (thermo regulation process that constantly balances both heat gain and heat loss from the body)	This was supposed to be controlled automatically when all the external parameters are fixed and maintained at a constant level.
Activity level (The body generates heat at widely varying levels depending on activity contributing to TP)	Controlled by allowing the participants to get involved in identical activities in each WS; comfortably seated and filling the questionnaire. (Participants were given guidelines to refrain from any hard physical activity prior to the trial)
Reactions to CO and other chemicals	Controlled by making the laboratory environment free from chemical stimuli.
Conduction from body	Direct contact with cold surfaces was avoided in WSs; The worktop and the chair to be seated made of timber. Specially designed identical slippers to avoid direct contact with the floor.

Table 4: Participant Variables of Colour perception

4.2.5) Factors leading to core body temperature resulting a change in Thermal Perception (DATA - Temporal Artery Temperature)

Ambient Temperature – (DATA – WS temperature)	Controlled via conducting the study in a controlled lab environment (26 ^{0}C).
Time of the day; Circadian rhythm	Test time zone (TTZ) included as a data in the model.
Individual variations	This was included in the model as Temporal Artery Temperature values. (TAT)
Age	Included in the regression model as a discrete ordinal variable.
Gender (Female: ovulation, pregnancy)	Controlled by selecting <u>only</u> a male sample to assure more accuracy in data.
Body Mass Index	BMI value included in the regression model.
Metabolic rate	BMI value included in the regression model.
Consumption of food	Controlled by instructing the subjects to have a specified balanced meal 2 hours prior to entering the WS.
Consumption of alcoholic drinks	Controlled via initial guidelines and the screening interview before entering the lab.
Physical activities	Controlled via initial guidelines and the screening interview before entering the lab.
Fasting	Controlled via initial guidelines and the screening interview before entering the lab.
Sleep deprivation	Controlled via initial guidelines and screening at the medical test and interview before entering the lab.
Sicknesses	Controlled via initial guidelines and screening at the medical test and interview before entering the lab.

Exposure to light	Will be controlled by providing the same lighting level within each work station (350 lux).
Regions of the body - Temperature can be varied in different regions of a body	Controlled by taking the body temperature measurement only from the forehead area (TAT). (Since the human body regulates skin temperature to balance the heat gain and heat loss, the use of skin temperature has significant potential as an index to the thermal sensation)
Topographical/ regional adaptation/Homeostasis to thermal conditions.	This was included in the model by including the average temperature of the region/home town (HT_Temp) in to the regression model.

Table 5: Core body temperature variables

4.3) Methodology

4.3.1) Population: The population tested under the study was undergraduate male students (age 20-30) of Faculty of Architecture, University of Moratuwa, Sri Lanka (n=321). The population was restricted only to males purposely as gender is suspected to be contributing to thermal perception due to the established correlation with core body temperature. The student population of Faculty of Architecture, having four diverse affiliated departments (Architecture, Integrated Design, Town and Country Planning and Quantity Surveying) was selected to draw the sample due to its rich mix of students representing a fair cross-section of the whole country; all the racial, religious, regional, climatic, socio, cultural, economic, and educational difference *(art, science, math and commerce based)*, so that the findings could be generalized to a greater extent.

4.3.2) Sampling technique – Stratified Simple Random Sampling

To obtain a statistically valid outcome, a random sample (n=111) from the male student population of Faculty of Architecture (n=321), University of Moratuwa with a 95% confidence level and 7.5% margin of error was proposed to undergo the final trial as mentioned below.

Population Size : 321 Margin of error : 7.5%

Confidence Level	Sample Size
80%	59
90%	87
95%	111
99%	154
99.9%	193
99.99%	217

Table 6: Justification for Sampling.

It was attempted to obtain a representative and statistically valid sample from the varying subpopulations (stratums; four departments) independently to represent the overall population; faculty of architecture as a whole via adopting a stratified sampling technique. During the stratification process the subjects per stratum were allocated considering the sample fraction; ratio of sample size to population size (Dodge, 2003) (Arch- 28, Des-22, QS-52 and TCP-10).

Once the numbers were decided the subjects within each department was selected via simple random sampling. A preliminary sample consisting of 155 students were drawn initially via simple random sampling, keeping tolerance for possible dropouts due to absenteeism, withdrawals, unforeseen circumstances, and holidays and not meeting the set eligibility criteria during the screening process. After going through three rigorous screening processes the 111 most eligible subjects to face the trial were selected out of the preliminary sample.

Ethical clearance: Using humans as subjects vitally needs ethical clearance. A letter of consent was distributed among the randomly selected male subjects (n=155) explicating the details of the investigation; objectives, procedures, impacts and contact persons.

Eligibility criteria: The randomly selected initial sample (n=155) was screened via three rigorous screening processes done based on a fixed eligibility criteria setup, referring to literature within the process of selecting the best suiting subjects and further to collect a database with most accurate data from the subjects;

A) First screening via self report: A preliminary screening of the subjects was done based on the set eligibility criteria by means of a questionnaire survey. It was attempted to select subjects with normal health via self-reporting to proceed with the next level of screening.

Note: 21 subjects withdrew due to personal, health, absenteeism and reasons and 9 subjects were identified to have long term illnesses. Out of the 155 subjects, only 125 proceeded to the 2nd screening.

Fig: 1 – Medical Checkup

B) Second screening- Medical check-up: The participants selected for the second screening (n=125) had to go through a general health check up (as specified by the eligibility criteria) done by an experienced medical practitioners.

Medical Examination Criteria:

a) Height, Weight, BMI.
b) Vision; Normal / Impaired/Colour Blind.
General health condition of each subject; heartbeat, pulse rate, respiration rate, blood pressure…etc.
c) Health conditions leading to high/low body temperature; Hyperthyroidism, hypothyroidism, endocrine issues, infections, hormone /chemical imbalances, skin problems, cardio vascular problems, swellings, kidney disorders.
Note: 5 subjects were detected to be colour-blind (The colour blind subjects were sent to the final trial and studied separately in order to explore possibilities of CTP beyond vision. The other subjects who got through the second screening were given a set of guidelines to be followed, (designed based on literature review) before coming to the trial.
C) Third Screening: Personal interview before the trial: Took place just before entering the lab for the trial. Each subject was interviewed to identify his medical/health/psychological

condition to determine the eligibility. It was inquired whether the subjects have adhered to the set guidelines provided duly to them to become eligible for the trial.
The best fitting (n=111) were selected through the aforementioned 3 staged screening process.

Clothing: Specially designed lab kit: The subject's were dressed in a specially designed black coloured comfortable linen lab kit and comfortable lab slippers (black) ensuring identical body coverage with identical materials and colour. The lab suit design was done using the standard measurements used for lab kit in the theaters of Durdans Hospital, Sri Lanka.

Fig; 2 – Especially Designed Lab Kit

Lab Design: The laboratory was designed by converting an existing studio of Faculty of Architecture (20' x12' x 11'), in to a controlled environment where colour Workstations (WS) were installed. It was designed to control all the external factors pertaining to thermal/colour perception as established via literature.

Fig 3; Colour Lab

Work Station Design: The WSs were identical in every aspect other than its applied colour. 4'x4'x5' WSs were made with 2mm thick timber planks fixed on to a frame of 1'x ½' thick timber members. Each WS is three sided and includes a simple work top (1 ½'x 4') done with the same method of construction placed at a height of 2 ½' from the ground level. Each WS was initially coated by filler with an identical thickness and the two paint coats were applied on top (Matt finish). Colour selection was done based on the RGB colour model. Three identical timber chairs were kept in each WS for the subject to sit comfortably and engage in the task given.

4.3.3) Experimental research design; A Randomized, crossover experiment

The study adopted an experimental research design to investigate the impact of colour red and blue on human thermal perception. In doing so, a crossover design was integrated. A crossover trial allocates subjects randomly to study arms where each arm consists of a sequence of two or more treatments/exposure given consecutively (Sibbald, 1998).

BR/ RB Crossover trial: In the current investigation the colour of workstations was manipulated by the experimenter to test its impact on the dependant variable; (CTP) while controlling all the predictor variables. Thermal perception of randomly selected 111 healthy male subjects was tested under two different colour treatments; Red (R) and Blue (B). The simplest crossover model was adopted in the trial; BR/ RB. Explicitly, subjects in BR study arm were exposed to blue colour first followed by red colour and vice versa in the RB study arm.

Drawback: Carryover effects: The principal drawback of the crossover trial is that the effects of one treatment may "carryover" and alter the responses to subsequent treatments.

Usual approach to preventing this is to introduce a washout period; no treatment period between consecutive treatments which is long enough to allow the effects of the initial treatment to wear off (Sibbald, 1998).

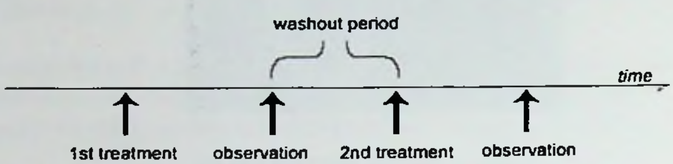


Figure.4. washout period Source: Sibbald, 1998

White workstation (WWS): To overcome the carryover effects, a white work station was introduced to the research design. While providing a washout period for the subject, the WWS provides a control environment for the trial as well. It was expected that being a neutral colour, a white environment will control, neutralize and settle the subject to reach his normal/basal psychophysiological level, especially core body temperature (CBD). Prior to entering the colour WS for the first treatment each subject was kept inside the white WS for 10 minutes until he reached his basal temperature level. Then, in case of the RB study arm he was first exposed to the red WS for 15 minutes. In order to washout carry over effects from the first treatment he was sent back to the white WS for another 10 minutes. Once the subject reached a constant/basal temperature level again he was sent to the next treatment; blue work station for another 15 minutes.

Fig 5: White workstation to neutralize and washout carryover affects

Fig 6: A subject in BWS

Fig 7: A subject in RWS

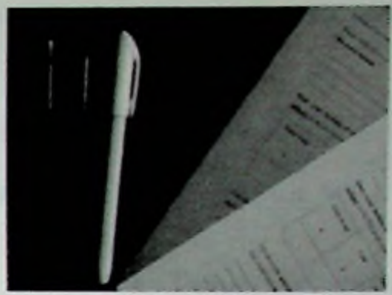


Fig 8 - Questionnaires and the pens were of selected with the corresponding colour
Source: Author

Laborotary was maintained in controlled conditions; fixed room temperature (26°C), lighting level (350 lux) and fixed interior finishes (matt) and colour (black).Around 10 research subjects were tested per day and equal numbers of subjects were allocated to both study arms (RB study arm = 5 and BR study arm = 5)

The temperature readings were taken via non invasive thermal monitoring system using a Temporal Artery Thermometer (TAT). Forehead temperature readings were taken in 2 minutes intervals until the subject reached none fluctuating /constant reading while in the WWS. When it comes to temporal artery temperature readings, the base line is identified as 99.6 °F (Hegner, Acello and Caldwel, E. 2012) where the normal range is established to be 97.4°F – 100.1 °F (Exergen,2006). Temperature readings were taken at 5 min intervals in the Red and Blue WSs. To facilitate the same activity/metabolic level in each WS, the subjects were guided to fill an identical questionnaire while they were seated and exposed to each colour. Papers on which the questionnaire was printed and the pens placed in each WS were of the same corresponding colour.

The subjects rated their thermal perception in a 5-point likert scale provided to them in the questionnaire. Meanwhile they reported their psychological condition triggered by exposure to each colour WS (thoughts, feelings, emotions and memories related to the colour of the workstation) and suggested activities they would prefer to perform within each WS.

Outdoor temperature was monitored per research unit with the use of two digital thermometers (Testo 174 T-). The surface temperature of WS was measured using non invasive infra red thermal monitoring system via FLIR i60 infra red industrial camera.

5) Data Analysis Protocols.

The investigation involved both both quantitative and qualitative data.. Some of the data were collected during the screening process via self report questionnaire, medical checkup and the interview just before the trial, namely level of practical and theoretical exposure to colour (Loe), vision (Vis), religion (Rlgn), race (Rce), study stream followed for A/L s (A/L_SS), favorite colour (Fvc), sensitivity to warm conditions (Sen_Warm), sensitivity to cool conditions (Sen_Cool), rate of sweating (Ros), average temperature of the home town (temp HT_Temp), body mass index (BMI), age.

The rest of data collected during the trial were,

Quantitative data; Temporal artery temperature in RWS and BWS (RTAT, BTAT), surface temperature of RWS and BWS (R_SFT / B_SFT), outdoor temperature (OT), test time zone (TTZ).

Qualitative data: Thermal perception in RWS and BWS (RTP and BTP) were recorded in a 5-point likert scale. Thoughts, feelings, emotions associated with RWS and BWS (R_Psy/ B_Psy) and preference of being in RWS and BWS (R_Pre, B_Pre) were recorded in the questionnaire.

5.1) Data collection method and tools

5.1.1) Temporal artery temperature - Forehead temperature; Temporal Artery Temperature (TAT) in°F (to represent core body temperature)

a) Method: Thermographic Measurement Technique - Non-Invasive Infra red thermal monitoring system.

b) Tool/ Equipment: Exergen Temporal Artery Thermometer (Temporal Scanner)
This thermometer obtains accurate infrared readings of temporal artery blood flow.

Figure: 9– Obtaining temporal artery temperature readings

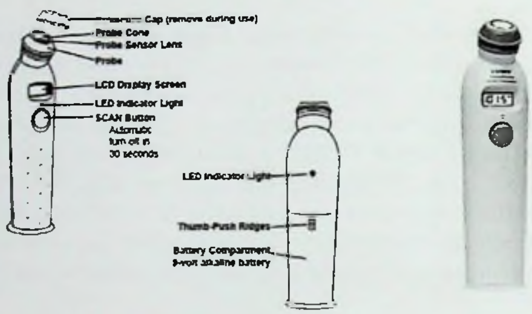


Figure 10:Temporal Scanner 2006 –User guide Source: Exergen,

5.1.2) Outdoor temperature (OT)- Testo 174T - Mini Data Logger Temperature

a) Method: The outdoor temperature was monitored at the information desk located just outside the lab where the 3rd screening interview took place.

b) Tool/Equipment: Testo 174T - Mini Data Logger was placed at the reception desk to measure OT. This digital thermometer possess a factory calibration;

Reference value of 25.0oC is measured as 24.9oC.

Measuring range	-30 to +70oC
Accuracy	±0.5oC (-30 to +70oC)
Operating Temperature	-30 to +70oC
Storage temperature	- 40 to +70oC
Resolution	0.1oC

Figure 11: Testo 174T-Mini Data Logger

5.1.3) Surface temperature of WSS (RSFT/BSFT)- FLIR i60: infrared thermal imaging camera

a) **Method:** Surface temperature of each WS monitored for any possible changes every time a subject enters the WS.

b) **Equipmet:** FLIR i60 non invasive infra red camera

Temperature Range	- 4°F to 662°F (-20°C to 350°C)
Temperature Accuracy	±2°C or ±2% of Reading
Emissivity Table	0.1 To 1.0 (Adjustable)
Thermal Sensitivity	(N.E.T.D) <0.1°C at 25°C

Figure12: FLIR i60: High-Temperature Thermal Imaging camera
Source: http://www.tequipment.net/Flir60.html

5.1.4) Perceived Temperature (RTP and BTP)

a) **Method :** The participants were requested to rate their thermal perception inside each of the three WSs (warmness/ coolness).

b) **Tool/Equipment:** A 5 – Point likert scale used for the subjects to rate the TP following the ASHRAE thermal sensation scale (5 hot (Very warm), 4 warm, 3 neutral, 2 cool,1 cold (very cool).

5.1.5) Time

a) **Method:** The trial took place as per a fixed time schedule. Accordingly the test time; the time which the subjects entered the lab as well as the time intervals the temperature reading were taken (2 minutes/5 minutes) were recorded in the data sheet.

b) **Tool/Equipment:** A digital clock was used in taking down the time.

5.1.6) Thoughts, feelings, emotions associated with each colour : 'Psy'-Factor
The subjects were requested to write down their thoughts, feelings, emotional and memories triggered via each colour in the identical questionnaire given in each workstation.

5.1.7) Activities preferred to perform in each workstation: In order to identify the suspected relationship between perceived thermal environment and human activities, the subjects were requested to suggest activities they wish to perform in each workstation on the same questionnaire where they had to rate their thermal perception. **(Pre factor)**

6) Results and Discussion:

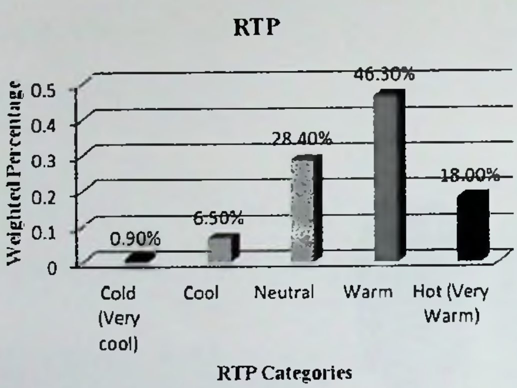


Chart 1- RTP weighted percentages

Data was initially entered on to Microsoft Excel and then transferred into SPSS software. The complete database of 111 subjects was weighted to be valid for the total population of Faculty of Architecture (n=321). All the qualitative data was interpreted, coded and transferred into quantitative data in the form of categorical variables.

6.1) Thermal Perception RTP/BTP

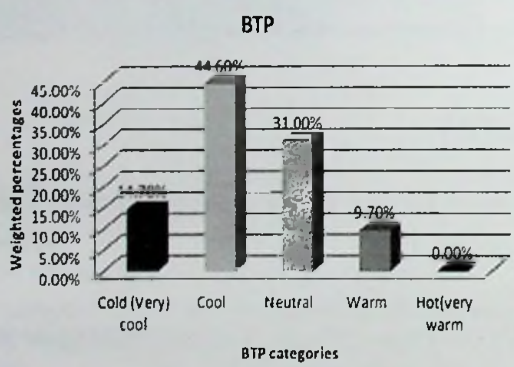


Chart 2- BTP weighted percentages

Supporting the theory of warm colours, 64.20% perceived RWS to be warm (46.3%) / hot (18%).
Only 7.4% subjects perceived red to be cool. However 28.4% subjects perceived red to be neutral. So it can be seen that a majority has perceived RWS as warm. On the other hand supporting the theory of cool colours 59.30% were found to witness a cool (44.6%) / cold (14.7%) BTP. Significantly none has rated BTP to be very hot and only 9.7 % has perceived BWS to be warm. Anyhow another 31% have rate BTP to be neutral.

Comparing RTP against BTP of all the subjects tested, the theory of warm cool dichotomy was re affirmed.

RTP was found to be warmer than BTP. The graph clearly demonstrates the trend line of RTP values lying on a higher level than BTP. As hypothesized, BTP is found to be cooler and RTP to be warmer. Therefore the study supports the hypothesis that the perception of red as warm and blue as cool can be generalized.

Eventhough it was expected to observe a different behavior, the above finding was in parallel with the reseponses of colourblind subjects.

80% of the colourblind subjects repotrted to perceive a warm TP and 0% cool RTP. 20% rated it to be neutral. But contrastingly, BTP has been neutral for the majority of colourblind's (60%) while only 40% has perceived BWS to be cool. No one perceived BWS to be warm. Colourblind subjects, though theoritically cannot see colour, has experienced a thermal perception similar to normal subjects. But they seem more responsive to red then blue. This finding suggests that colour associated thermal perception has linkages beyond visual pereception.

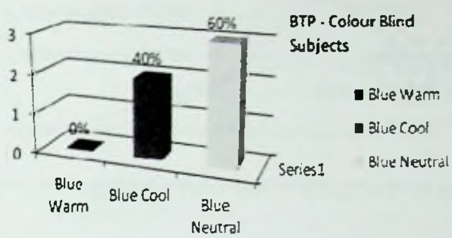


Chart 3- BTP Colour Blind Subjects

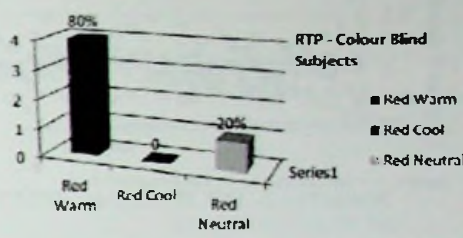


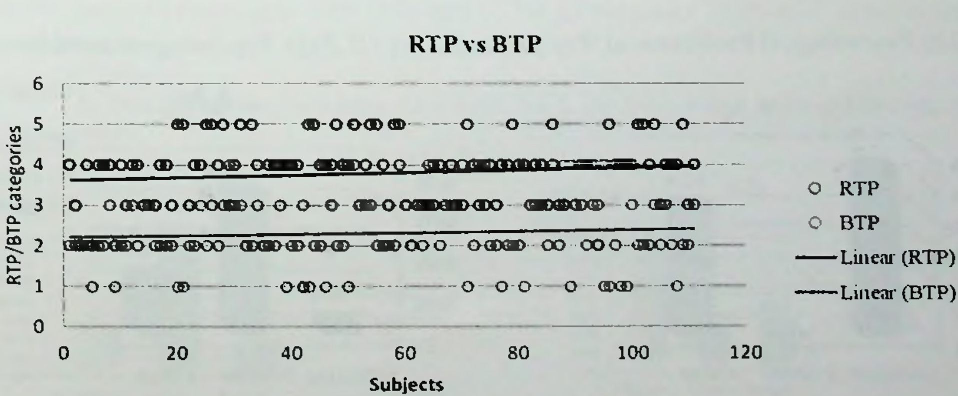
Chart 4- RTP Colour Blind Subjects

6.2 Significant findings associated with IVs.

6.2.1) Comparison between RTAT and BTAT:

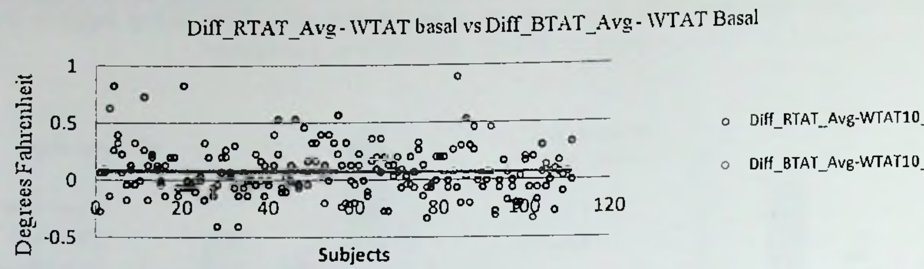
It was hypothesised that RTP/BTP could be a repercussion of a variation of a biological reaction. It was suspected that there can be a variation in body temperature (which was measured by TAT) triggered by colur stimuli. The study witnessed that the change of RTAT or BTAT caused by colour stimuli is insignificant. The difference between the basal TAT in WWS and the average temperature reading in RWS;RTAT and BWS;BTAT was graphed in ascending order.

The range of increase or decrease of RTAT was : - 0.4 °F – 0.8 °F, Average: 0.083 °F.
The range of increase or decrease of BTAT was: - 0.4 °F – 0.9 °F , Avg: 0.08 °F.



Scatter Plot 1- RTP Vs BTP

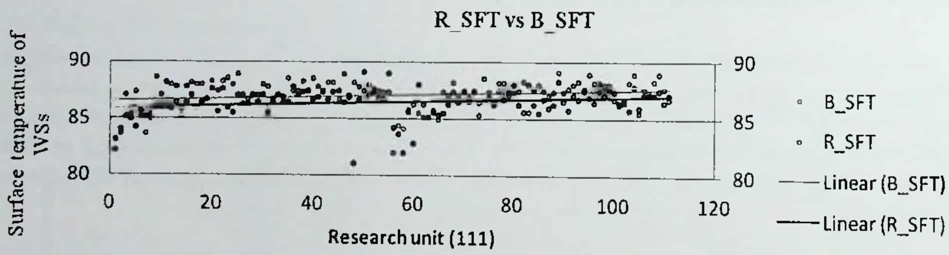
Eventhough it was hypothetically explicated that red could trigger a drastic increase in RTAT and blue could decrease BTAT , it was revealed that the increase/decrease of body temperature (TAT) due to colour stimuli was insignificant. This suggests that the warm/cool diachotomy of colour is not a consequence due to a body temperature variation. As per the scatter polt both trend lines overlap and run horizontaly suggesting no relationship between RTP/BTP and TAT. Accordingly it is suggestive that body temperature variation is not significant for CTP as suspected.



Scatter Plot 2 - Diff_RTAT_Avg - WTAT basal Vs Diff_BTAT_Avg – WTAT basal

6.2.2) Impact of surface temperature on CTP:

Significantly B_SFT was found to be higher than R_SFT, witnessing the potential of colour to contribute to the external thermal milieu.
Average of R_SFT = 86.46 °F, Average of B_SFT= 87.17 °F , Diff = 0.71 °F



Scatter Plot 3: Comparision between B_SFT and R_SFT

6.2.3) Psychological Predictors: a) 'Psy' factor (R_Psy /B_Psy): Psychological condition

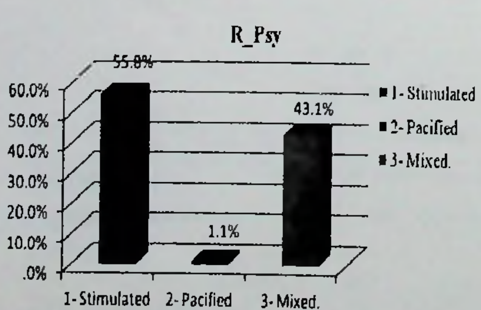


Chart 5- R_Psy weighted Percentages

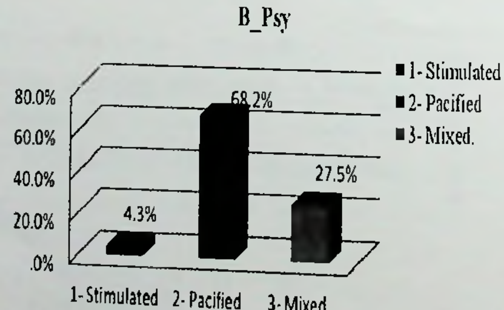


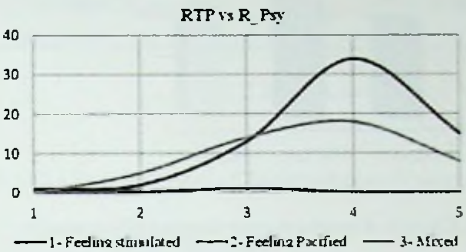
Chart 6- B_Psy weight percentages

R_Psy: For instance 55.8% subjects experienced stimulated psychological level while only 1.1% was found to be pacified. Another 43.1% demonstrated a mixed psychological.

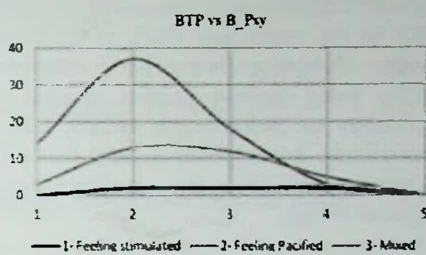
B_Psy: 68.2% (majority) was found to be pacified in BWS and only 4.3% witnessed to be stimulated. Another 27.5% experienced a mixed level.
Parallel to the duality of RTP and BTP, dual psychological reactions against exposure to red and blue was demonstrated.

It was found that the 'Psy' factor plays a significant role for both RTP and BTP.

B) Preference; R_Pre/B_Pre: As per the graph, it was seen that having a stimulated



Graph 1- RTP vs R_Psy



Graph 2- BTP vs. B_Psy

Psychological level has contributed to a warm RTP and a pacified state for a cool BTP

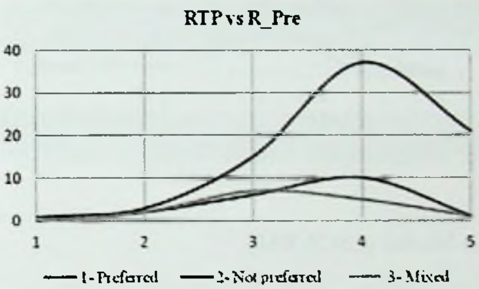
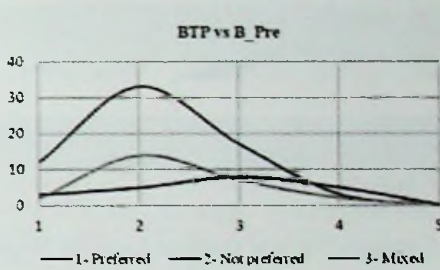


Chart 4- BTP vs B_Psy



Graph 3- RTP vs R_Pre

A majority (66.6%) did not prefer exposure to RWS. Only 20.8% was found to prefer being in RWS and 12.6% had mixed thoughts in terms of preference. Contrastingly, a majority (60.9%) preferred exposure to BWS while only 17.3% did not prefer. 21.8% were found to have mixed thoughts.

R_Pre /B_Pre; Preference associated with RWS/BWS too were found to have a bearing on RTP and BTP

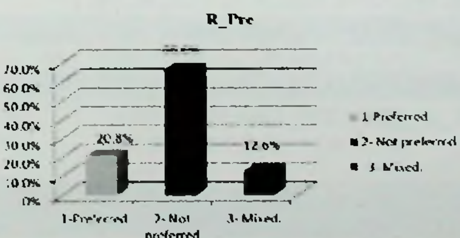


Chart 7- R_Pre weighted

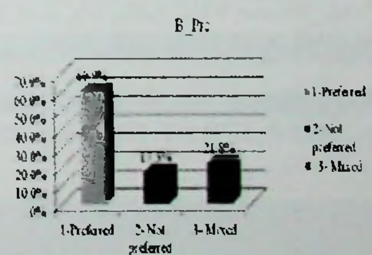


Chart 8- B_Pre weighted

It can be seen that the subjects who have not preferred the exposure to RWS has a tendency to perceive a warm RTP. Conversely the subjects who preferred exposure to BWS has propensity to perceive a cool BTP.

c) Favorite colour

55.7% subjects' favorite colour was found to be a cool colour and only 22.9% and 21.4% had warm colours and neutral colours respectively as their favorite colour. The subjects having cool / neutral favorite colours demonstrated tendency to rate RWS to be warm and BWS to be cool equally. Deviating from above, subjects having warm favorite colours showed a probability of perceiving a neutral RTP. Accordingly, it was clearly evident that the probability of CTP to be a psychological response is high.

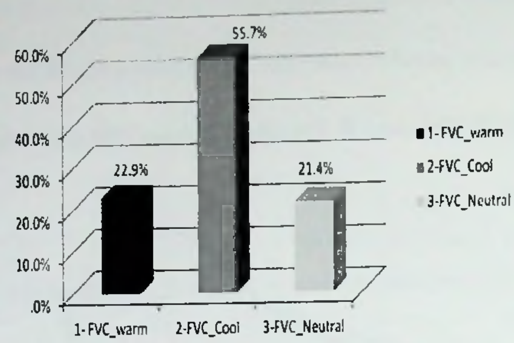
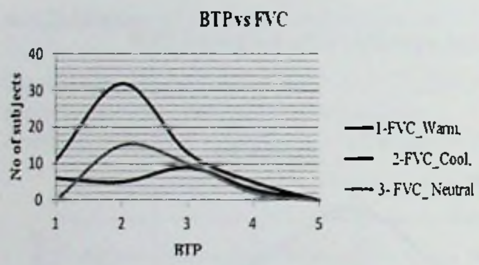
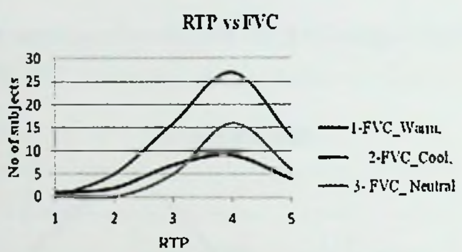


Chart 9- Favorite colour weighted Percentages



Graph 5- BTP vs FVC



Graph 6- RTP vs FVC

6.3) Complex Sample Ordinal Logistic Regression Model (CSOLRM)

In order to provide a statistically significant explanation for RTP and BTP, especially to understand the most powerful predictors of RTP and BTP, a literature review was conducted to find a best fitting regression model. As per literature, considering the fact that the output variable is a discrete variable having 5 ordinal categories (Lunsford, 1993 and Pasta, 2013) an ordinal logit regression model was adopted. Since stratification was done in sampling to represent the total population of 4 departments in a fair and reasonable manner the model was further specified in to a Complex Sample Ordinal Logistic Regression (Liu and Koirala(2013). CSOLR model was run for both RTP and BTP separately considering all the predictors as summarized below.

RTP-AL_Streme, FVC, LoE, Vis, RoS, Sen_Warm, Sen_Cool, Rlgn,,Rce, TTZ, R_Psy , R_Pre, BMI, R_SFT, OT, HT_Temp, Diff_RTAT_AvgWTAT10_1and Age

BTP - AL_Streme, FVC, LoE, Vis, RoS, Sen_Warm, Sen_Cool, Rlgn,,Rce, TTZ, B_Psy , B_Pre, BMI, B_SFT, OT, HT_Temp, Diff_BTAT_AvgWTAT10_1and Age

6.3.1) Classification of Dependant Variable – RTP and BTP

DV	Variable label	Value label	Variable type and level of measurement
RTP	Thermal Perception in Red Workstation	1- Cold (*Very cool*), 2 - Cool , 3 - Neutral, 4 - Warm, 5- Hot (*Very Warm*)	Discrete – Ordinal scale
BTP	Thermal Perception in Red Workstation	1- Cold (Very cool), 2 - Cool , 3 - Neutral, 4 - Warm, 5- Hot (Very Warm)	Discrete – Ordinal scale

Table 7: Classification of Dependant Variable – RTP and BTP

6.3.2) Classification of Independent Variables - Discrete variables— Ordinal Scale

IVs	Variable label	Value label
LoE	Level practical and theoretical exposure to colour (Pre conceived ideas)	1-Good, 2-Moderate, 3-Poor
Ros	Rate of Sweating	1- -High 2- Normal, 3- Low
Age_M	Age	1- (20-22), 2- (23-24), 3- (25-30)
Sen_Warm	Sensitivity to warm conditions	1 Very high to warm, 2 High to warm, 3 Normal to warm
Sen_Cool	Sensitivity to cool conditions	1 Very high to warm, 2 High to warm, 3 Normal to warm
LoE	Level of practical and theoretical exposure to colour	1-Good, 2-moderate, 3-less
R_Psy B_Psy	Psychological state associated with RWS/BWS	1- Feeling stimulated, 2- Feeling Pacified, 3- Mixed.
TTZ	Test Time Zone	1- 8 .30 -9.30 a.m/ 2 - 9.30-10.30 a.m/ 3-10.30-11.30 a.m / 4-11.30 a.m - 12.30 pm / 5 - 12.30-1.30 p.m / 6- 1.30 - 2.30 p.m/ 7- 2.30 p.m - 3.30 p.m/ 8 - 3.30 p.m-4.30 p.m/ 9- 4.30-5.30 p.m/ 10 - 5.30 - 6.30 p.m

Table 8: Classification of Independent Variables - Discrete variables – Ordinal Scale

6.3.3) Classification of Independent Variables - Discrete — Nominal Scale

IVs	Variable label	Value label
Vis	Vision	1- Normal, 2- Impaired, 3- Colour Blind
Rlgn	Religion	1-Buddhist, 2-Chatholic/Christian, 3-Islam, 4-Hindu
Rce	Race	1-Sinhalese 2-Tamil 3- Muslim/ Moor
A/L _SS	Subject streams followed for A/Ls	1-Maths, 2-Arts, 3-Bio, 4- Commerce
Dept	Department	1-QS, 2-Archi, 3-Design, 4- TCP
FVC	Categorization of favorite colours in to warm, cool and neutral colours	1- FVC_Warm, 2-FVC_Cool, 3- FVC_ Neutral
R_Pre B_Pre	Preference associated with RWS/BWS	Preferred 2- Not preferred 3- Mixed.

Table 9: Classification of Independent Variables - Discrete — Nominal Scale

6.3.4) Classification of Independent Variables - Continuous – Interval scale

IVs	Variable label	Value label
BMI	Body Mass Index	Value in Kg/M2
Diff_RTAT _ Avg / Diff_BTAT _ Avg	Difference between the basal WTAT value and RTAT/BTAT average value: Total increase of decrease of RTAT/BTAT in °F.	Value in °F
R_SFT/ B_SFT	Surface Temperature of RWS/BWS	Value in °F
OT	Outdoor temperature	Value in °F
HT_Temp	Average temperature of Hometown (In year 2012)	Value in °F

Table10 : Classification of Independent Variables - Continuous – Interval scale

The predictor variables pertaining to the dependant variable were investigated based on a 95% confidence interval considered in sampling process. A null hypothesis (H_0) and an alternative hypothesis (H_A) were tested. H_0 hypothesized that none of the predictors will have a correlation to the outcome variable. ß explains the coefficient for the fitted line. Accordingly the hypothesis can be defined as follows.

(H_0): $\beta_i = 0$ for all i.   (H_A): $\beta_i \neq 0$ for at least one coefficient.

The following parameters were used to decide on the goodness-of-fit and the strength of the model.

Test of Model effects table: Explains the significance (P value) of each predictor variable to the dependant variable (RTP/BTP). A predictor is considered as significant if the p value is less the 0.05.

"pseudo-R" statistic describes the strength of the model. It is designed to explain something similar to what R-squared tells in ordinary least-squares regression, that of the proportion of variance accounted for in the dependent variable based on the predictive power of the independent variables (predictors) in the model (Denis,2010). R^2 in ordinary least square regression is a fraction between 0.0 – 1.0 where 0.0 explains that no linear relationship between variables. Anyhow pseudo-R values cannot be interpreted exactly as one would interpret R-squared in ordinary least-squares regression (Denis, 2010). As clarified by Cohen, Cohen, West & Aiken (2003 as cited in Denis, 2010), and ". . . we caution that all these indices are not goodness of fit indices in the sense of'proportion of variance accounted for, in contrast to R-squared in OLS regression".

Correct Classification Rate (CCR): A parameter used to test model fit. CCR is a percentage value and higher the value, better the model fit will be. For instance 50% CCR describes that 50% of the predictors are explained by the model. As per literature a good model should achieve a CCR higher than 50% CCR.

Initially a full model was run for both RTP and BTP including all the predictor variables mentioned above in order to test the significance with the outcome variable. Secondly excluding the insignificant predictors suggested the model was re –run to identify the most significant predictors pertaining to RTP/BTP.

6.4) Significant CSOLR Model – RTP

Tests of Model Effects

Source	df1	df2	Wald F	Sig.
AL_Streme	3.000	105.000	2.872	.040
FVC	2.000	106.000	5.779	.004
Rlgn	3.000	105.000	3.201	.026
R_Psy	2.000	106.000	7.105	.001
R_Pre	2.000	106.000	7.873	.001

Dependent Variable: RTP (Ascending)
Model: (Threshold), AL_Streme, FVC, Rlgn, R_Psy, R_Pre
Link function: Logit

Pseudo R Squares

Cox and Snell	.334
Nagelkerke	.364
McFadden	.164

Dependent Variable: RTP (Ascending)
Model: (Threshold), AL_Streme, FVC, Rlgn, R_Psy, R_Pre
Link function: Logit

Classification

Observed	Predicted					
	1	2	3	4	5	Percent Correct
1	.000	.000	.000	2.900	.000	.0%
2	.000	3.400	8.700	8.700	.000	16.3%
3	.000	.000	39.300	49.900	1.900	43.1%
4	.000	.000	14.000	125.500	9.100	84.5%
5	.000	.000	.000	48.600	9.100	15.8%
Overall Percent	.0%	1.1%	19.3%	73.4%	6.3%	55.2%

Dependent Variable: RTP (Ascending)
Model: (Threshold), AL_Streme, FVC, Rlgn, R_Psy, R_Pre
Link function: Logit

6.5) Significant CSOLR Model – BTP

Tests of Model Effects- BTP Significant Model

Source	df1	df2	Wald F	Sig.
AL_Streme	3.000	105.000	9.483	.000
B_Psy	2.000	106.000	4.032	.021
B_Pre	2.000	106.000	3.694	.028
Age_M	1.000	107.000	8.435	.004
B_SFT	1.000	107.000	6.820	.010

Dependent Variable: BTP (Ascending)
Model: (Threshold), AL_Streme, B_Psy, B_Pre, Age_M, B_SFT
Link function: Logit

Pseudo R Squares

Cox and Snell	.371
Nagelkerke	.405
McFadden	.188

Dependent Variable: BTP (Ascending)
Model: (Threshold), AL_Streme, B_Psy, B_Pre, Age_M, B_SFT
Link function: Logit

Classification

Observed	Predicted				
	1	2	3	4	Percent Correct
1	18.900	23.500	4.800	.000	40.0%
2	7.600	113.500	22.200	.000	79.2%
3	1.900	48.300	46.000	3.400	46.2%
4	.000	1.900	20.400	8.700	28.1%
Overall Percent	8.8%	58.3%	29.1%	3.8%	58.3%

Dependent Variable: BTP (Ascending)
Model: (Threshold), AL_Streme, Age_M, B_Psy, B_Pre, B_SFT
Link function: Logit

6.6) Output Summary:

RTP significant predictors: R_Psy, R_Pre, AL_Streme, FVC, Rlgn,
BTP significant predictors: B_Psy, B_Pre, AL_Streme, Age_M, B_SFT.
Revealing the outputs of the CSOLR model, it was found that the significance of the predictors differ from RTP to BTP, while certain factors remain common. A major finding of the study is the common significance of psychological factors (Psy and Pre) for both RTP and BTP. Further the preconceived learnt ideas due to prior exposure and education (AL_Stream) dominate as common. Apart from that, favorite colour has become as significant parameter only for RTP, which is another psychological response. BTP was found to be affected by the subject's age. Affirming the hunch that SFT could have an impact of RTP/BTP, it was found that B_SFT is significant for BTP. The supposition of a possible increase/decrease of human body temperature due to colour stimuli was not revealed.
RTP models gave correct classification for 55.2% of the predictors studied. BTP provided classification for 58.3% suggesting a good model fit.
RTP Model - R^2 = .334 (Cox and Snell); .364 (Nagelkerke).
BTP Model - R^2 = .371 (Cox and Snell); .405 (Nagelkerke).

7) Concluding Remarks

To recapitulate, the findings of this experimantal research supports the warm cool diachotomy of colour perception. In general terms it can be explained that red is perceived as warm and blue as cool. The findings further demonstrate dual psychological reactions against exposure to red and blue. The supposition of CTP as a consequence of body temperature difference is non-valid. Unexpectedly, it was found that the B_SFT was higher than R_SFT witnessing impact on CTP. B_SFT is found to be highly significant on a cool BTP compared to the significance of R_SFT on a warm RTP. Colour-blind subjects too demonstrated a warm RTP, suggesting CTP's links beyond vision. It was found that psychological factor plays a significant role amidst all the predictors considered on CTP.

The study in a nutshell supports the hypothesis that the perception of red as warm and blue as cool can be generalized. The emergence of colour associated thermal perception was found to be a complex combination of several layers; learnt, psychological, external as well as certain un-revealed factors. Considering the revealed nature of CTP, conducting further research on the possibility of colour to manipulate perceived thermal as well as psychological milieu demanded by human activities intended in built environment and for energy conservation is highly recommended.

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