Colors for optimal thermal comfort in university study hall - interdisciplinary theoretical and practical studies

I Marinova * and A Ivanova
Faculty of Architecture, University of Structural Engineering & Architecture (VSU)
"L. Karavelov", 175 Suhodolska St., 1373 Sofia, Bulgaria

*E-mail: m_vania@hotmail.com

Abstract. Improving thermal comfort trough interior color design is a contemporary energy efficiency and healthy living environment tendency. The article considers scientific-applied task of choosing a color design for a specific university seminar hall. The concept integrates areas of architecture and design, color science, physics, chemistry, material science, psychology, etc., in the context of aesthetics, light-reflecting qualities and physical and emotional impact of colors upon inhabitants. Optimal color design considers general principles applied to a specific environment and requires integrated approach and interdisciplinary theoretical and practical studies in order to improve the process of creating such an optimal solution. The report examines contemporary interior color design scope. Characteristics of university hall and the requirements they raise are studied. An overview of colors’ features as a means of improving thermal comfort is included. Stages of the design process and the involved specialists are listed. The advantages of nonlinear design process are applied. As result the succession and the degree of participation of different science fields specialists in the interdisciplinary theoretical and practical studies and in the choice of the final design are set.

1. Interior colour design scope
Contemporary interior color design is a complex task that meets requirements. In previous research authors differentiate colors in two groups according to the role they play in the living environment – traditional and contemporary [1].

1.1. Traditional role of colors in the living environment
Traditionally, colors carry information about the surrounding objects and denote separate functional zones in a single space. Most popular colors application is according to their aesthetic value. They also are given a symbolic meaning. At a later stage, the colors in the living environment are applied also according to the individual perceptions and preferences of the inhabitants.

1.2. Contemporary color application
Modern research reveals color properties which determine new application possibilities. The ability to influence the perception of objects and spaces leads to color application in order to visually complement and alternate the living environment characteristics. The application of colors according to their reflective properties assists the distribution of light and the accumulation of heat from solar electromagnetic energy by building elements. Most contemporary trend is the application of colors according to their physiological and psychological impact on the inhabitants.
2. Characteristics of a university study hall in reference to thermal comfort optimization

Permanent residents are students, 20 and more persons, average aged about 22 years. Temporary residents are professors, time of stay and age vary.

The variety of activities is also diverse - lecturing, conducting exercises, independent working, socializing, recreating.

The combination of various activities and occupants requires combined approach towards improved working and study environment [3] and meeting inhabitants’ preferences [4]. Significant amount of objective and subjective factors are to be taken into account in order to create optimal thermal comfort.

Traditional color design of a university study hall meets the requirements for aesthetics, for emphasizing the functional zoning and in some cases - for light redistributing. Table 1 compares the traditional color scheme in a study room with modern requirements.

| Modern requirements                                      | Traditional color design                        |
|----------------------------------------------------------|-------------------------------------------------|
| information about surrounding objects,                  | information about surrounding objects,          |
| functional zones marking                                 | functional zones marking                        |
| aesthetic value                                          | aesthetic value                                 |
| symbolic meaning                                         | -                                               |
| according to the perceptions and preferences of          | -                                               |
| inhabitants                                              |                                                 |
| visual supplementation and adjustment of                 | -                                               |
| living environment characteristics                       |                                                 |
| light distribution and heat storage                       | -                                               |
| physiological and psychological impact on the            | -                                               |
| inhabitants                                              |                                                 |
| new technologies in covering materials                   | -                                               |

The comparison illustrated in table 1 reveals that the application of colors according to those properties that contribute to increasing the thermal comfort of the occupants does not appear in the traditional color scheme of a study room.

3. Colors for optimal heat comfort in the living environment

Color, being a constant characteristic of interior, has rarely been considered for its thermal impact. Researches of color properties and of ways they influence the inhabitants reveal possible new functions in the architectural environment, which are directly related to improving energy efficiency.

Studies reveal that, when considering the psychological aspects of interior color design there are variations according to gender and age [4]. But they are little to none when physiological impact is concerned – colors have similar effects even if some of the inhabitants experience partial or complete color blindness [5].

When it comes to colors, three main characteristics to be considered – electromagnetically wave length, hue and saturation.

Physical property of colors is related mostly to the amount of solar radiation that is reflected or absorbed. Coloring structural elements in dark shades allows more solar energy to be accumulated by space surrounding elements and furniture. Disadvantage of dark surfaces is that they absorb and do not reflect light, so need for earlier switching on and greater intensity of artificial lighting appears.
Physiological effects include the stimulation of certain processes in human body, as well as some effects of synesthesia. Psychological impact on colors is related to a subjective comfort criteria trough variety of associations color tones and shades induce.

Generally warm colors (red, orange, yellow) are associated with warmth and light. The physiological effects of red and some shades of orange, for example, are increased adrenaline levels, increased heart rate, muscle contraction and, as a result, a rise in body temperature. As a result, the inhabitants of an environment with predominant shades of orange and red have lower requirements for comfort temperature levels [6]. This also makes warm colors not suitable for interior of rooms that receive large direct and indirect heat revenues in the summer, as they can lead to increased requirements for cooling and ventilation [1].

The lighter shades of cold colors - green, blue, purple are associated with water, space, coolness, etc. In addition, green and blue tones have a calming effect on the nervous system and slow down the heart rate, resulting in a slight decrease in body temperature [6]. The occupants of rooms with predominant green, blue and violet shades have reduced requirements for air conditioning in summer, but experience discomfort during the cold seasons [1].

As additional measures to enhance the energy-saving properties of colors, dyes with improved reflectivity in the field of ultraviolet and infrared rays [2, 11, 12, 13], as well as completely new materials that respond to external factors [2, 11, 12, 13] are being developed. Such materials have a positive effect on the radiation temperature in the premises. The combination of materials, textures and colors can help to optimize the movement of air in the room, thus improving the effective temperature [7].

4. Stages of interior color design process

Finding an interior color solution can be considered as consisting of three main stages:

- Theoretical studies - justification of the need to update the color scheme and preliminary studies;
- Practical studies - research and development of the architectural potential of the room and choice of color design;
- Site management and monitoring.

An intermediate stage of negotiations to reach a consensus between the participants in the renewal appears between first and second stages [8].

In the first stage of theoretical research, the introductory and fundamental activity is the justification of the need and desire of the inhabitants for a more comfortable and more productive environment, combined with the desire to increase energy efficiency. The stage continues with a study of economic and technological opportunities for realization. This activity clarifies which services and products are essential for the specific solution. Similar cases are studied and compared with the specific situation.

The second is a stage of practical researches. First, the physical characteristics and condition of the selected room are studied. In connection with the optimization of thermal comfort, emphasis is placed on the volumetric-spatial solution, proportions, the functional solution and the number and location of communication openings, height and facade participation in connection with calculating factor shape, building materials and covering layers of enclosing structures in order to calculate their heat transfer coefficient. Next the priorities of color design are determined and variants are developed. To help the analysis in order to select most optimal option, an analysis with the respective software products of a virtual model of the room is applied, as well as research on a physical model with indicators and properties close to the original materials. A variant of a color design that best meets the defined priorities is chosen. Specific design plans are developed. Next is drawing up a plan and organizing the implementation and determining the participants in this process. The final activity at this stage is the realization of the color solution.
The third stage covers the administration of the implementation process and the management and monitoring of the project. It includes control of repair activities and development of the site to achieve its optimal capabilities and also the management and promotion of the site and its maintenance.

A study of possibilities is done at each stage of the project. Its main purpose is to reduce the risk and to form the basis of detailed design. It includes study of similar successfully held projects, assessment of the current situation and the most appropriate development strategy and selection of a specific interior color design. Following is a decision for appropriate investment, approval of an approach for renewal and drawing up a project development program.

Each of the aspects of improving thermal comfort through interior color design project involves participation of specialists in various fields - optics, heat engineering, materials science, chemistry, mechanics, construction technology, medicine, biology, psychology, sociology, color science, finance, law, computer technology and more. Since it is a question of applying colors in a living environment, the intersection of all these areas is an architectural / design project. Mandatory permanent participation of users / occupants [9].

5. Participants in the process of optimizing the thermal comfort through an interior color design
The participants in the process are the residents, specialists-consultants and administrative authorities.

Studies reveal that occupants are the main driver of the process of finding an interior color solution. They are also the most active participant in the development, operation and further development of the specific site [9].

Sociological research shows that residents prefer to take the initiative to improve the environment they live in. They have a desire for change and a vision of what that change should be. They are the initiators of the organization of local organizations, which deal with the formation of the necessary teams of specialists, with the documentation process and the development of the sites. The improved living environment is a cause for pride, as people like to live in a place of which they have actively contributed [9].

Therefore, public participation and establishing the interests of people are a key factor in projects to improve thermal comfort through interior color design.

The role of administration authorities in the process of finding an interior color solution is mainly regulatory. Their main tasks and activities are:
- engagement in development programs;
- creation of normative and financial reliefs for stimulating the interest in improving the living environment;
- creation of organizations supporting and promoting these trends;
- creation of programs and funds for additional financing of projects for improvement of the living environment;
- creation of centers for information and communication with specialists

Specialists - consultants are the main participants in the processes of design, implementation and monitoring of thermal comfort through interior colors. The team must include diverse specialists - architects, civil engineers, economists, lawyers, brokers. During the different stages of the process of improving thermal comfort through interior color design some of them form the main and permanent core of the team and additional specialists are involved for temporary participation and / or one-time consultations. Practice shows that with such an organization, the team involved in the design process has a number of advantages, such as flexibility of solutions, the ability to work in a network and non-linear parallel development of the project stages [10].

Table 2 shows the groups of activities at each stage of the development of an interior solution and the necessary specialists-consultants for each stage.
Table 2. Specialists-consultants participation in activities and stages of interior color design development

| Stage                                | Activities                                                                 | Specialists-consultants                                      |
|--------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------|
| Preliminary study and justification  | Initiative, connection with specialists                                   | inhabitants                                                 |
| (theoretical studies)                | Defining the basic requirements of the inhabitants                        | inhabitants, architect / designer, psychologist, sociologist |
|                                      | Study of economic opportunities                                           | financier, lawyer                                           |
|                                      | Study of technological possibilities                                       | designer, technologist                                       |
|                                      | Exploring opportunities for realization                                   | architect / designer, constructor, technologist, financier  |
|                                      | Study of similar projects                                                 | architect / designer, constructor, financier                |
| Study of the potential of the room  | Physical characteristics and condition study                               | architect / designer, constructor                            |
| and realization of the color scheme  | Building materials study                                                  | architect / designer, constructor                            |
| (practical studies)                  | Setting priorities for a color scheme developing                          | inhabnants                                                  |
|                                      | Options, virtual and real practical studies development                    | architect / designer, constructor, psychologist, computer technology, materials science, biology, medicine |
|                                      | choice of a specific option                                                | inhabants, architect / designer, constructor, financier     |
|                                      | Design plans development                                                  | architect / designer, constructor, technologist, physicist, chemist, psychologist, financier |
|                                      | Organizing the realization process                                         | architect / designer, constructor, technologist, financier  |
|                                      | Color design completion                                                   | technologist                                                |
| Implementation, management and      | Management of the implementation process                                  | architect / designer, constructor, technologist, administration |
| monitoring of the project            | Project management and monitoring                                         | inhabants, architect / designer, constructor, financier, sociologist, administration |

6. Conclusions
Main conclusion from the present study is that the task of optimizing interior thermal comfort of university study room through color design is complex and requires knowledge in a wide range of areas. The factors that need to be considered are a significant number. Some of them relate to the properties of materials and structures and to the organization of elements and spaces. Another concerns the occupants, as well as their interaction with the living environment specifically in terms of optimizing thermal comfort.
It follows from the above that the participation of various specialists is a mandatory element for complete project implementation. The proven advantages of interdisciplinary participation and the ability of simultaneous multi-task process are also to be considered.

According to their degree of participation, the specialists are to be divided into three groups: permanent participants, temporary participants and occasional consultants. Table 2 clearly reveals that the main core specialists in this case are architects/designers and constructors. The active participation of the occupants/users at each stage of the process is also mandatory.

In the preliminary theoretical studies, it is necessary to include as temporary participants in the process specialists in the fields of finance and technology. Psychologists, sociologists and lawyers are to be involved as consultants.

At the stage of practical research as temporary participants are technologists, computer specialists, psychologists, financiers. Specialists in physics, chemistry, biology and medicine should be involved as consultants.

Acknowledgments
The studies in this report are funded by science-research project № 11, order № 256 / 27.05.2020. The authors express their gratitude to USEA (VSU) "Lyuben Karavelov", Bulgaria.

References
[1] Marinova I 2012 Color properties as a means of improving living environment comfort (Sofia: International Jubilee Scientific and Applied Conference 70 Years UACEG, report collection ISBN 978-954-724-049) pp 207 – 212
[2] Kumar A 2013 Advances in the Building Materials for Thermal Comfort and Energy Saving (Benham Science Publishers: Recent Patents on Engineering)
[3] Hohmann T 2006 New Aspects of Library Design (Netherlands: LIBER Utrecht University Library Open Access Journals)
[4] Costa M, Frumento S, Nese M and Predieri I 2018 Interior Color and Psychological Functioning in a University Residence Hall (Switzerland: Frontiers in Psychology)
[5] Hetiarachchi and Emmanuel R 2017 Colour as a psychological agent to manipulate perceived indoor thermal environment for low energy design ; cases implemented in Sri Lanka (Scotland: Passive Low Energy Architecture (PLEA) - Design to Thrive Conference)
[6] Goreva G 2016 Educational reference book on the subject of color science and color (Minsk: Belarusian State University) p 36. Amersfoort J, Balvert S, Hadlich S, Härter M and Liu F 2007 Investigating the effects of altered colour perception on mood
[7] Radivojević A, Dukanović B 2018 Material Aspect of Energy Performance and Thermal Comfort in Buildings (Energy resources and building performance) (Delft: TU Delft Open) pp 61-85
[8] 2019 Project Development Guide (Mosksw: Fund of the Unified Institute for Housing Development) pp 110-136 Manal O and Abowardah E 2016 Design Process & Strategic Thinking in Architecture (London: International Conference on Architecture & Civil Engineering)
[9] Jenkins P and Forsyth L 2009 Architecture, Participation and Society (Milton Park: Taylor & Francis Ltd)
[10] Novikova A 2015 Network form of architectural design organization (Nijnii Novgorod: Kazan State Architectural and Construction University)
[11] Koca G 2016 Interior Finishing Materials (Developments in Science and Engineering Chapter 43) ed R Efe, L Matchavariani, A Yaldir, L Levai (Sofia: St. Kliment Ohridski University Press) pp.588-601,
[12] Orf N 2009 Thermeleon (Greentech Media)
[13] Petrie T, Atchley J, Childs P and Desjarlais A 2007 Energy Savings for Stucco Walls Coated with Cool Colors (Oak Ridge: Oak Ridge National Laboratory)