Principles of passive solar architecture as means of improving health and thermal comfort aspects of indoor environment

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Abstract. The estimates are that we spend majority of our lifetime indoors. Therefore, the quality of indoor environment is crucial to our health. Thermal comfort is amongst the most energy-related aspects of comfort since the energy requirements for heating and cooling refer to more than a half of energy needs in buildings. Passive solar architecture, emerged from the archetypal builders’ responses to the natural environment, by using the energy of the sun for heating and cooling in the most economical and rational way- by applying the laws of physics. The key passive solar architectural principles aimed at achieving thermal comfort presented in the paper are: adaptive thermal comfort (the comfortable indoor temperature levels adjusting to the outside temperature), thermal zoning (variety in disposition and orientation of the different functional zones), and thermal mass (using building materials with ability to effectively store heat), all aimed at enhancing energy efficiency and providing a healthy indoor environment.

1. Introduction

Architecture influences our health in many ways, most significantly through various kinds of comfort: thermal, visual, acoustic, indoor air quality, psychological aspects of comfort. Since we spend most of our lifetime inside buildings (up to 90% in developed countries), this impact is of a crucial importance to our health and wellbeing.

Thermal comfort is the most energy related aspect of comfort, referring to heating and cooling which covers most of energy needs in buildings. At the same time, it is of vital importance to our health, since means of heating and cooling affect not only maintaining body temperature in an optimal range, but also the air quality indoors. The principles of passive solar architecture such as: adaptive thermal comfort (comfortable indoor temperature depending on the outdoor air temperature), thermal zoning in buildings (variety of thermal zones in buildings adjusted to the requirements for thermal comfort) and thermal mass...
(building elements and materials absorbing, storing and radiating heat), can enhance not only thermal performances of a building, but also the state of health and wellbeing of its occupants. In addition, these passive sustainable design measures rely on renewable source-energy of the sun, hence, they contribute to the reduction of fossil fuels usage in buildings, and consequently to preservation of the environment.

2. Passive solar architecture and thermal comfort

The fire (heat) is an archetypal, constitutive, cosmic element on which depends vitality of living beings and survival of human kind. In sustainable design, it refers to the energy of the sun (the greatest renewable natural resource and inexhaustible source of heat and light) as well as to the thermal performances of buildings, i.e. consideration of thermal gain/loss according to the building materials, organizational scheme, and application of passive architectural measures- heating and cooling elements and systems; all aimed at providing optimal conditions of thermal comfort indoors.

Life exists in a very limited temperature range of human body spanning only a few degrees. Metabolism creates heat, mostly during the day (especially by physical activity), the least during night. Overheating has a deteriorating impact to our health and may lead to exhaustion and eventually to the lethal outcome. On the other hand, cooling down too quickly can make us feel unpleasantly cold which can lead to hypothermia. Thermal comfort is associated with the sense of optimal agreeability (neither too hot, nor too cold) when a thermal balance of the body is achieved.

Passive solar architectural principles are aimed at providing thermal comfort for building occupants and saving energy for heating and cooling in buildings by maximizing heat gain during winter and minimizing it during summer. These principles rely on the laws of physics in relation to the means of heat transfer: radiation, conduction, convection and evaporation (condensation). In addition, building orientation and solar exposure are of the highest importance in architectural design.

The means of providing thermal comfort affect our health not only in terms of maintaining body temperature at optimal levels, but also by influencing indoor air quality and having psychological implications to our state of wellbeing. The principles of passive solar architecture having positive effect to our health are: adaptive thermal comfort (adaptive approach to thermal comfort), thermal zoning and thermal mass (heating by radiation and conduction).

2.1 Adaptive thermal comfort

People have an innate tendency to adapt to changes of the environmental conditions. For example, immediately after changing the surroundings, we perceive peculiar, unpleasant fragrances and noice, but we get used to them quickly and soon after they fade out in the ambience background. The same applies to adaptive approach to thermal comfort. If a thermal change occurs in a way to produce discomfort, people react in ways which tend to restore their comfort. [1]

In heated and cooled buildings, comfortable temperature levels typically range from 22°C to 25°C, regardless of the outdoor temperature. However, in a free-running (naturally ventilated) buildings comfortable temperature levels are dependent on the outdoor temperature, raising and falling in parallel with it (Figure 1). The difference between the outdoor and indoor comfortable temperature levels is only a few degrees, which is the foundation of the variable, adaptive standard, determined by the equation:

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T_c = 13.5 + 0.54 \times T_o \quad [1]
\]

\(T_c\)- comfort temperature indoors
\(T_o\)- monthly mean of the outdoor air temperature
Figure 1. Comfort temperatures as a function of outdoor temperature for buildings which are free-running (A) and with heating and cooling (B). [1]

The adaptive thermal standard refers to a wide span of thermally comfortable environments in relation to the outdoor temperature in free-running buildings, which implies that thermally comfortable environmental conditions can be achieved by applying passive architectural measures, i.e. by applying passive architectural principles we activate our natural capacity to adapt to the environmental conditions which enables us to reduce (or maybe even eliminate) artificial heating and cooling systems, leading to a healthier and more energy efficient indoor environment.

Adaptive thermal comfort is achieved by natural ventilation. This sustainable design method enables not only the similarity of indoor and outdoor temperature levels and thus adaptive approach to thermal comfort, but also the improvement of the indoor air quality: higher oxygen and lower carbon dioxide concentration, removal of the unpleasant odours and polluters (air particles), reduction of the relative humidity level and the maintenance of the thermal comfort when outside temperature is high. In the absence of the natural ventilation a so called Sick Building Syndrome (SBS) occurs, described as medically undefined health disorder where subjective constraints decrease working ability and the state of wellbeing. On the contrary, a research of SBS shows that natural ventilation triggers significantly less symptoms or health disorders compared to the mechanical ventilation or entirely air conditioned buildings (Figure 2). [2]
2.2 Thermal zoning
The need for change and constant sensory stimulus in the environment is our indigenous, psychological need, originating from the natural environment, a complex, endlessly dynamic world we derived from. Therefore, we need sensory change in artificial environments. Hence, indoor environments of a higher level of dynamics, complexity and variability (thermal, visual, sound) appear to be more stimulating and beneficial to our health. On the contrary, monotonous environments lead to lethargy and sensory inactivity, as well as to slower brain activity, which triggers negative emotional and psychological states.

Thermal zoning, a passive solar architectural principle, refers to distribution of thermally various zones according to the orientation, i.e. depending on the needs of solar exposure. Daily zones, rooms occupied mostly during the day time (living rooms, dining rooms, classrooms, etc.), should benefit from direct solar exposure with south or south-east orientation. Night zones (bedrooms) should not be oriented towards south. Furthermore, thermal zoning depends on the use of space. Rooms mostly unoccupied during the day (bathroom, storage, utility room, technical room) should not have maximum solar exposure, but rather be oriented towards north, or even be surrounded by rooms, with no direct connection to the outside. These thermal zoning principles enable creation of thermally various, dynamic indoor environments through the temperature differences between rooms, thus positively affecting our health.

2.3 Thermal mass (heating by radiation and conduction)
The heat transfers through conduction, convection, radiation and evaporation (condensation). Radiation and conduction warm up body deeply, while convection heats only the surface layers. This is a reason why we never feel pleasantly warm inside air-conditioned buildings. The estimates are that heat transfer through radiation from wall surfaces in a room has 34 percent more direct impact on the thermal comfort of building occupants, compared to the indoor temperature level. [3] If there are sources of radiant heat, thermal comfort

Figure 2. The results of SBS study of J. Röben (health disorders in relation to the ventilation systems: natural ventilation, mechanical ventilation and air conditioning). [2]
is achieved even when air temperature is 18°C. The comfort zones in relation to the predominant means of heat transfer (convection and radiation) are presented in Figure 3, where can be seen that radiant sources of heat provide wider span of comfort zone in relation to heating by convection. [4] Air circulation during heating by convection enables spreading of dust particles in the air, together with other particles harmful to our health. In addition, fans and canals of air-conditioning units destroy negative ions, which deteriorates indoor air quality and our state of wellbeing.

![Figure 3](image.png)

The Sun is main source of heat due to radiation. Passive solar architectural methods include captivation and accumulation of solar energy, so that it can be used later for heating indoor space. The accumulation of solar energy is achieved through thermal mass (heated surfaces and volumes of water or solid matter that captivate, store and later radiate heat). Among the most efficient passive solar systems is Trombe wall, painted in dark colours (preferably black) in order to absorb more solar energy. If the radiant mass is heated water, it transfers heat through all its volume, not just on the surface level as in the case of solid matters.

3. Conclusions

Principles of passive solar architecture such as adaptive thermal comfort (adaptive approach to thermal comfort), thermal zoning and thermal mass (heating by radiation and conduction), are preferable in terms of energy efficiency and health. Adaptive approach to thermal comfort triggers our indigenous adaptive mechanisms, enabling wider range of comfortable indoor air temperatures depending on the outside temperature, in opposition to the air-conditioned buildings where comfortable indoor temperatures are not outside related, and air quality indoors is at much lower level. Also, since heating and cooling requires more than a half of the total energy needs in buildings, through adaptive approach to thermal comfort, we achieve significant energy savings. Thermal zoning, a principal of passive solar architecture which relies on building
orientation and solar exposure in order to maintain thermally comfortable indoor environment is beneficial to our health and wellbeing since it enables thermal variety and sensory stimulus indoors, thus satisfying our psychological need for a change. Heating by radiation and conduction is the most healthy and efficient way of heating. Implementation of passive solar systems including elements of high thermal mass which absorb, store and radiate heat, leads to not only significant energy savings, but also to more easily achieved thermal comfort indoors, without deteriorating the air quality level. All of these principles are favorable in terms of preserving the environment (using renewable, inexhaustible natural resource of heat- solar energy) and health (achieving thermal comfort, fulfilling our psychological need for a sensory change in the environment, enabling better air quality indoors compared to the artificial sources of heat), which all contributes to a healthier, greener, more agreeable environment, as well as to the sustainable development.

4. References

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