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Causes and Architectural Solution to Heat and Non-conducive Air Condition in the Congregation Space of Worship Facilities (Pp. 164-178)

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Pedagogical Content Knowledge: A Key Factor in Teaching Painting

Abstract

Passive Solar building aspire to maintain interior thermal comfort all through the sun's daily and annual cycles at the same time as reducing the requirement for active cooling and heating systems. Passive solar building design is one fraction of green building design and does not consist of active systems such as mechanical ventilation or photovoltaic; on this premise of green solution lay architectural explanations and way out of the problems of heat and non conducive air condition in interior spaces irrespective of the facility type and use. This paper outlines the importance of creating and or finding green resolutions to thermal discomfort using the tool of architecture rather than machines in congregation spaces. It also reveals the demonstration/ case study of an existing worship facility experiencing severe internal thermal discomfort during worship activities, including processes required to finding solution against such challenges.

Key words- Heat and Insulation

Introduction

The scientific basis for passive solar building design has been developed from a combination of climatology, thermodynamics (particularly heat transfer), and human thermal comfort (for buildings to be inhabited by humans). Specific attention is directed to the site and location of the dwelling, the prevailing climate, design and construction, solar orientation, placement of glazing-and-shading elements, and incorporation of thermal mass. While these considerations may be directed to any building, achieving an ideal solution requires careful integration of these principles. Architecture not machinery can achieve significant energy savings without necessarily sacrificing functionality or creative aesthetics. In fact it is for this reason that this newly coined term, known as Architectural Science or Building Science, has become an upcoming subject area in most schools of Architecture worldwide. The ability to achieve these goals simultaneously is fundamentally dependent on the seasonal variations in the sun's path throughout the day. This occurs as a result of the inclination of the earth's axis of rotation in relation to its orbit. The sun path is unique for any given latitude. Generally the sun will appear to rise in the east and set in the west.

In Northern Hemisphere non-tropical latitudes farther than 23.5 degrees from the equator:

- The sun will reach its highest point toward the South (in the direction of the equator)
- As winter solstice approaches, the angle at which the sun rises and sets progressively moves further toward the South and the daylight hours will become shorter
- The opposite is noted in summer where the sun will rise and set further toward the North and the daylight hours will lengthen.

The converse is observed in the Southern Hemisphere, but the sun rises to the east and sets toward the west regardless of which hemisphere you are in.

In equatorial regions at less than 23.5 degrees, the position of the sun at solar noon will oscillate from north to south and back again during the year.

In regions closer than 23.5 degrees from either north-or-south pole, during summer the sun will trace a complete circle in the sky without setting whilst it will never appear above the horizon six months later, during the height of winter.

The 47-degree difference in the altitude of the sun at solar noon between winter and summer forms the basis of passive solar design. This information is combined with local climatic data (degree day) heating and cooling requirements to determine at what time of the year solar gain will be beneficial for thermal comfort, and when it should be blocked or prevented for same reason. By strategic placement of items such as glazing and shading devices, the percent of solar gain entering a building can be controlled throughout the year.

One passive solar sun path design problem is that the sun is in the same relative position six weeks before, and six weeks after, the solstice, BUT due to "thermal lag" from the thermal mass of the Earth, the temperature and solar gain requirements are quite different before-and-after the summer-and-winter solstice. Movable shutters, shades, shade screen, or window quilts can accommodate day-to-day and hour-to-hour solar gain and insulation requirements.

Careful arrangement of rooms completes the passive solar design. A common recommendation for residential dwellings is to place living areas facing solar noon and sleeping quarters on the opposite side.

Passive Solar Thermodynamic Principles

Personal thermal comfort is a function of ambient air temperature, mean radiant temperature, air movement (wind chill, turbulence) and relative humidity (affecting human evaporative cooling). Heat transfer in buildings occurs through convection, conduction, and thermal radiation through roof, walls, floor and windows.

Convective Heat Shift

Convective heat transfer can be beneficial or detrimental. Uncontrolled air infiltration from poor weatherization can contribute up to 60% of heat gain during summer and 40% of heat loss during winter; however strategic placement of operable windows or vents can enhance convection, cross-ventilation, and summer cooling when the outside air is of a comfortable temperature and relative humidity. Filtered energy recovery ventilation systems may be useful to eliminate undesirable humidity, dust, pollen, and microorganisms in unfiltered ventilation air.

Natural convection causing rising warm air and falling cooler air can result in an uneven stratification of heat. This may cause uncomfortable variations in temperature in the upper and lower conditioned space, serve as a method of venting hot air, or be designed in as a natural-convection air-flow loop for passive solar heat distribution and temperature equalization. Natural human cooling by perspiration and evaporation may be facilitated through natural or forced convective air movement by fans, but ceiling fans can disturb the stratified insulating air layers at the top of a room, and accelerate heat transfer from and hot attic hence the need for architectural means and ways.

Radiating Heat Shift

The main source of heat transfer is radiant energy, and the primary source is the sun. Solar radiation occurs predominantly through the roof and windows (but also through walls). Thermal radiation moves from a warmer surface to a cooler one. Roofs receive the majority of the solar radiation delivered to a house. A cool roof, or green roof in addition to a radiant barrier (Ceiling) can help prevent your attic from becoming hotter than the peak summer outdoor air temperature.

Windows are a ready and predictable site for thermal radiation. Energy from radiation can move into a window in the day time and out of the same window at night. Radiation uses photons to transmit electromagnetic waves through a vacuum or translucent medium. Solar heat gain can be significant even on cold clear days. Solar heat gain through windows can be reduced by insulated glazing, shading, and orientation. Windows are particularly difficult to insulate compared to roof and walls. Convective heat transfer through and around window coverings also degrade its insulation properties. When shading windows, external shading is more effective at reducing heat gain than internal window coverings.

Western and eastern sun can provide warmth and lighting, but are vulnerable to overheating in summer if not shaded. In contrast, the low midday sun readily admits light and warmth during the winter, but can be easily shaded with appropriate length overhangs or angled louvers during summer. The

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amount of radiant heat received is related to the location latitude, altitude, cloud cover, and seasonal / hourly angle of incidence.

Another passive solar design principle is that thermal energy can be stored in certain building materials and released again when heat gain eases to stabilize diurnal (day/night) temperature variations. The complex interaction of thermodynamic principles can be counterintuitive for first-time designers.

Site Definite Concerns during Design

- Latitude and sun path
- Seasonal variations in solar gain e.g. cooling or heating degree days, solar insulation, humidity
- Diurnal variations in temperature
- Micro-climate details related to breezes, humidity, vegetation and land contour
- Obstructions / Over-shadowing - to solar gain or local cross-winds

Concepts

Let us examine some idea of heat gain and loss within the building interior space and how they ultimately contribute to comfort or discomfort of occupants.

I. Insulation and Heat Flow

A. Purpose of insulation

1. controls heat flow
2. prevents condensation
3. improves comfort (by eliminating hot or cold surfaces and consequential radiant heat flow between the human body and those surfaces)

B. How heat flows

1. Conductivity (conduction)

- k = conductance per inch (per sq ft, per 1 deg F, per hour)
- C = conductance per actual thickness, l, so C = k/l
- U = conductance of entire assembly

Resistance, R = 1/C or l/k; i.e., it is the inverse or reciprocal of U-value.

$R_t = R_1 + R_2 + ... + R_n$

To find U: $U = 1 / R_t$. Note that U is *not* equal to $C_1 + C_2 +...+ C_n$

Heat flow, Q = U x A x (temp. differential) expressed in BTU/hr. units.

Example of U-value calculation for a 10' x 10' wall consisting of three layers as follows:

- Outside sheathing with R = 0.5
- Insulation with R = 19 (typical for 2x6 walls)
- Inside finish with R = 0.5

Note that these numbers are adjusted to make the calculations easier, but they are close to reality. $R_t = 0.5 + 19 + 0.5 = 20$.

$U = 1 / R_t = 1/20 = 0.05$.

Calculate heat loss assuming an outside temperature of 20 deg F and an inside temperature of 70 deg F (so the temperature differential is 70 - 20 = 50 deg F).

Q = (0.05) (100) (50) = 250 BTU/hr.

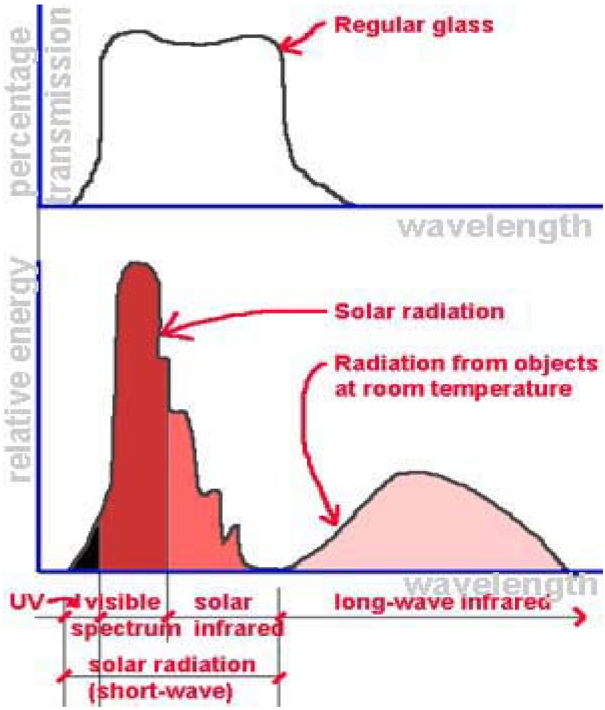
Note that separate heat flow calculations could be made for all parts of the enclosure, including walls, roofs, windows, etc., and the resulting partial heat flows can simply be added together to obtain the heat flow for the entire building, or any given space. It is this number that then determines the size of a heating or cooling unit.

2. Radiation

- Includes light, radio, x-ray, uv, infra-red, etc.
- travels through air or vacuum
- warm objects radiate heat

- hot objects (e.g., the sun, or a fire) radiate both light and heat
- colors absorb light energy differently (e.g., dark colors absorb more of the electromagnetic spectrum; whereas light or reflective colors absorb less)

Note greenhouse effect where frequencies generated by the sun (a hot object) can penetrate glass, after which they are absorbed within interior building elements and re-emitted at a longer wavelength (i.e., as "heat") which gets trapped within the glazed space (see image below).



3. Convection

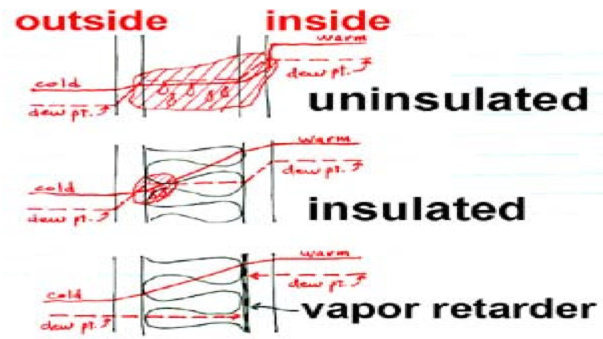
- heat moved by currents of air
- warm air rises relative to cold air
- other forces can power convection including: any pressure differential (e.g., wind, stack effect, mechanical ventilation)

Note that air is a good insulator if convection is prevented:

- plastic foams trap air in bubbles
- in fiber insulations, air molecules "cling" to fiber surfaces

Relationship between insulation, vapor retarders, and condensation is illustrated in the image below, with cold exterior conditions:

- Top image shows un-insulated wall with added humidity inside (i.e., higher dew point temperature). Condensations occur within wall (interstitial condensation) where actual temperature is at or lower than dew point temperature.
- Middle image shows effect of added insulation; actual temperature inside wall increases along gradient, but interstitial condensation is still a risk.
- Bottom image shows vapor retarder added on warm side of wall, creating a discontinuity in the vapor pressure gradient, so that the dew point temperature remains lower than the actual temperature throughout the wall, and condensation will not occur.



Source: Jonathan Ochshorn, 2007

Note that both the actual temperature and the dew point temperature increase from left to right (exterior to interior conditions) along gradients determined by the thermal resistance of the various wall components (in the case of actual temperature); and by the permeability of the various wall components (in the case of dew point temperature). For example, if we assume that the sheathing and finish materials have R = 0.5 and the insulation has R = 19 in the middle diagram, and then the temperature change within the insulation is 19/20 or 95% of the total change. Similarly, if we assume that the two surface materials (sheathing and drywall, for example) have equal permeability, then the dew point temperature curve would increase equally within those two materials, and would not increase at all within the insulation, which is assumed to be completely permeable. The reverse is the case of hot exterior conditions.

II. Ventilation

Ideally, one would "ventilate" the building envelope on the side opposite the vapor barrier, so that any stray humidity would not build up within the wall. In traditional wood-frame construction, a shingled wall provides such a ventilated space, since humidity can work its way through the relatively permeable outer layers of the wall. In sloping rafters or unheated attic spaces, the ventilation should be made more explicit, using soffit and ridge vents to promote the flow of air below the roof surface.

From the concept above we can easily come to the deduction that heat activeness in building interiors could be affected and influenced to increase by the following factors.

Aspect that can Raise Heat Activeness in Facilities Interior Spaces:

- Deviation from ideal orientation and north/south/east/west aspect ratio
- Excessive glass area ('over-glazing') resulting in overheating (also resulting in glare and fading of soft furnishings) and heat gain when ambient air temperatures go up
- Installing glazing where solar gain during the day and thermal losses during the night cannot be controlled easily e.g. East-facing, angled glazing, skylights
- Thermal gains through non-insulated or unprotected glazing
- Lack of adequate shading during seasonal periods of high solar gain (especially on the East wall)

- Open staircases leading to unequal distribution of warm air between upper and lower floors as warm air rises
- Low building ceiling surfeit (Building interior space volume)
- Inadequate weatherization leading to low air infiltration
- Lack of and incorrectly installed, radiant barriers during the hot season.

Insulation materials that are not matched to the main mode of heat transfer (e.g. undesirable convective/conductive/radiant heat transfer)

Demonstration/ Case study

In the light of the above exposed conceptions, a case study of Full Gospel worship facility in Mekelle Ethiopia was carried out to determine the root problems of heat and un-conducive air condition in the congregation space during worship activities. The investigation was conducted based on the facility visit, first hand experience, physical measurements and members/ witness interviews. But for easy understanding, I have divided it into three major segments

a. Observation
b. Experimentation
c. Result/ Recommendations

Observation

This outlines the findings and general noting of the situation as discovered during the visit of the facility.

- Building Dimensions: Effective Height – 4300mm (see diagram 1)
    - Width - 20450mm
    - Length - 35450mm

- Wind direction effect on facility: Good
- Cross ventilation : Very Good
- Hoods/ Shading devices : Not available
- Natural Conservers: Good but absence of trees
- Windows: Low level: Very good, well positioned and good sizes 1500 mm from floor level prefix
- High level: Very good, well positioned and adequate in number/quantity

- Windows projection mode and Open able bay: Interior projection and less than half open ability.
- Glass: Clear white and cast white glass
- Ceiling: All aspects are conspicuously absent and unavailable.

Experimentation
This is the direct application of the observation as against some of the earlier stated concepts, known principles and theories. The aim being to determine their general appropriateness and the root causes of the problem.

Building Menstruations:
Appling mathematically proven standards of length and breath against the height of congregational spaces in worship enclosures, (which states that every worship enclosure with minimum length of 30meters must have a double volume of minimum2/3 the breath dimension) it was discovered that the effective height of the facility interior is slightly inadequately and does not provide for efficient air conventional current required to maintain good natural air condition within the interior space of the facility

Wind Direction: - This was found good and as such cannot be improved upon as against the facility due to its natural nature.

Cross Ventilation: is very good and was been found very effective and efficient in the air condition transfers with in the facility interior.
Hoods/ Shading devices: Not available in the facility thereby allowing unnecessary glare to penetrate into the congregation, space increasing the heat intensity in the interior

Natural Conservers: - Available but can not improve the building orientation, protect and serve as sun screen against ultra violent sun rays, reducing the humid nature of the air quality in the facility interior.

Windows: Both the high and low level windows in the facility was found and judged very good, well positioned and adequate in number, providing very effective cross-ventilation and serves adequately for the much required conventional current. But the low level windows where found to be 1500mm high from the present floor prefix instead of 1200mm standard. (See diagram 2)

Projection mode/Open able Bay: The interior projection mode is good but gives less than half open able bay which is inadequate to further improve the volume and amount hot air being expelled during worship activities through this channel.

Glass: The glass types are found to be relatively good and do not contribute much to the heat strength of the space in question.

Ceiling:

Type: There is no existence of ceiling/ceiling type on the facility and as such allowing full heat transmission from the Aluminum roofing sheet down to the worship interior. A ceiling type as shown in diagram 1 is proposed so as not to encroach into the available space volume existing.

Material: The ceiling material must be a good insulator, aesthetically satisfied, affordable and available in the local market with very simple installation process and low in maintenance cost. This will completely eliminate thermal transmission of any sort from the heat conducting roofing sheets.

Vent: Air vents (quantity to be determined on site) must be provided at appropriate positions on the ceiling to take-out brewing hot air within the circulation space to be created between the roofing materials and the installed ceiling material/sheets.

Color: The chosen ceiling materials should bear a bright color, radiating good sense of humor and psychological feeling of worship to prevent absorption and enhance reflection of heat waves in the congregation interior space.

At the end of careful examination and assessment of all the facility aspect that can contribute to the excessive heat gain as experienced within the facility interior space during worship activities, the below stated recommendations where made according to the strength of their anticipated effects.

Recommendations

- Ceiling: The introduction of ceiling and all its aspects as highlighted with experimentation is strongly recommended as this with serve as a total insulator from the heat being transferred from the aluminum roofing sheets down to the facility interior.

- Flooring:- The elevation of the floor level prefix to bring it to 1200 mm is also strongly recommended because it will elevate worshippers to the natural air movement path across two apposite windows (See Diagram 2)

- Windows: - It is also strongly recommended that the open able bay of the high level windows be increased to full open ability. This will effectively increase the volume of hot air it takes out of the worship interior space during summer and could be easily closed to conserve heat during winter as desired.

Conclusion

The successful adoption of non mechanical solutions to heat in worship buildings can be very challenging especially in this part of our world where the machine availability, cost and its regular maintenance is in doubt. Architecture and Architects should always strive to inculcate from the design stage solutions to such challenges in what I can term climatic responsive architecture. In cases of existing buildings/ facilities experiencing heat problems in the interior space, it is equally advisable for the owners/ management board of such facilities to have the advice and input of trained professionals who can:

- assess the condition of the facility,
- evaluate the significant Building elements that should be preserved or reused,
- prioritize the objectives,
- understand the impact of new interior climate conditions on the congregation
- understand the visual and physical and psychological impact of proposed installations,
- identify maintenance and monitoring requirements

It is worthy of note that recommendation number one has been decided on by the management board of the facility which was also strongly stated in the earlier discussion (Radiating heat shift) above.

Finally, thermal insulation or super insulation (type, placement and amount) assists in significantly reducing unwanted heat transfer.

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