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Passive design strategies for cold and cloudy climate

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Abstract

Improving energy efficiency through technological advances has been the focus for next generation of buildings. However, living in cold climates is more energy demanding than in hot climates. The main idea is to cut energy consumption by passive strategies. The study focuses on most cost effective means of providing heat to building. The innovative combining passive solar applications, when included in initial building design, adds little or nothing to the cost of building, yet has the effect of realizing a reduction in operational costs and reduced equipment demand.

Keywords: passive solar heating, rock bed, sun space, strategy, earth berm, building form, human comfort.

Introduction

In recent years, interest in making use of energy from the sun has accelerated enormously. The problem is how to convert the energy at reasonable cost into a reliable usable form for heating and cooling of buildings.

Optimal study takes the passive form of architecture to create comfortable living spaces. The mechanism of heating and cooling equipment is usually referred to as a system. In passive building designs the system is integrated into the building elements and materials – the windows, walls, floors, and roof are used as the heat collecting, storing, releasing, and distributing system. Storage of solar energy is a challenge than collecting. Combining strategies together with respect to orientation, form, and other design concepts, will lead to a sustainable approach. For study purpose, the climatic data of Shimla, Himachal Pradesh, India is considered.

Climatic data for cold and cloudy – Shimla

Solar Radiation

time	Jan	Feb	March	Apr.	may	June	July	aug	Sept	Oct	nov	Dec
5am		***	***	***	***			***	***	***	***	***
6am	***	***	***	***	68.88	66.91	55.86	***	***	***	***	***
7am	***	36.50	69.19	191.14	275.54	200.72	139.66	61.15	68.25	166.95	58.89	***
8am		164.27	253.69	382.27	413.31	289.93	195.52	122.31	250.26	333.91	117.77	***
9am	157.27	310.28	392.07	573.41	551.08	379.14	251.38	183.46	386.77	500.86	294.43	179.2822
10am	283.09	456.30	530.44	764.55	688.85	468.35	307.24	244.61	523.27	667.82	490.72	388.4448
11am	366.97	584.07	622.69	955.68	757.73	512.96	335.17	305.77	614.28	834.77	588.87	448.2056
12noon	387.94	638.82	668.82	955.68	757.73	512.96	335.17	305.77	659.78	588.87	608.49	478.086
1pm	366.97	584.07	622.69	955.68	757.73	512.96	335.17	305.77	614.28	448.21	588.87	448.2056
2pm	283.09	456.30	530.44	764.55	688.85	468.35	307.24	244.61	523.27	667.82	490.72	388.4448
3pm	157.27	310.28	392.07	573.41	551.08	379.14	251.38	183.46	386.77	500.86	294.43	179.2822
4pm	41.94	164.27	253.69	382.27	413.31	289.93	195.52	122.31	250.26	333.91	117.77	***
5pm	***	36.50	69.19	191.14	275.54	200.72	139.66	61.15	68.25	166.95	58.89	***
6pm	***	***	***	***	68.88	66.91	55.86	***	***	***	***	***

(blue)	<304.58 W/SQ.MT
(orange)	304.58W/SQ.M - 609.16W/SQ.M.
(red)	>609.19W/SQ.M.

Fig. 1 Radiation square for Shimla – hourly radiation on horizontal surface, (W/m^2)

Bio-climatic chart

A bioclimatic chart is a preliminary analysis tool used during the early planning stages of a building project to identify the most efficient passive cooling and heating strategies based on the climate and location of a building site.

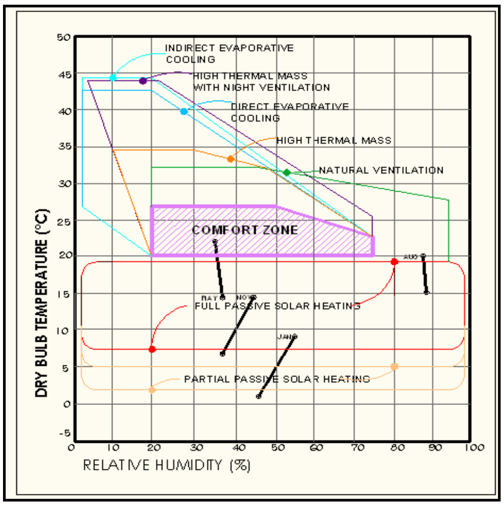

Fig.2 Bioclimatic chart for Shimla

Throughout the year the temperature is low, so solar passive heating strategy is needed to bring it in comfort zone.

Design strategies for cold and cloudy climate

The main criteria while designing are its built form, orientations, wall area, window area, thermal insulation, and thermal mass. Thermal strategies are to maximize warming effects of solar radiation and to reduce impact of winter wind.

Site scale:

Micro climatic phenomena

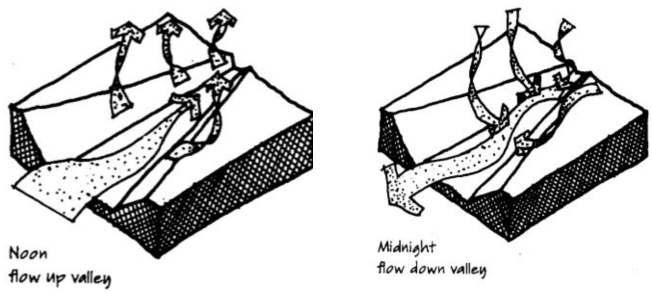

Fig.3 – (left) in valleys wind blows uphill during day (Right) at night the flow reverses

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Slope location based on climate

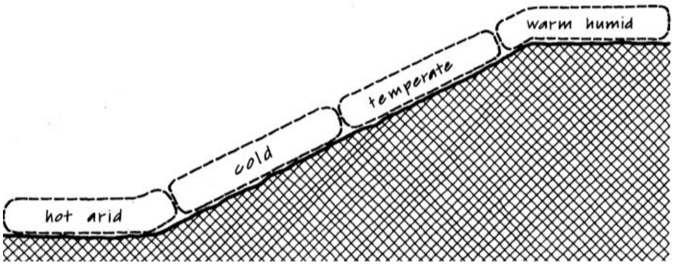

Fig. 4 - Solar radiation varies with terrain respect

Aspect is the combined slope and orientation of a surface in relation to the sun. A surface perpendicular (normal) to the suns rays receive most radiation per unit of surface area. Therefore, south facing slopes receive more sun than other orientations, easterly slopes receive more morning sun, and westerly slopes receive more afternoon sun. Steeper slopes generally receive more sun than flat areas.

Building scale:

Building orientation

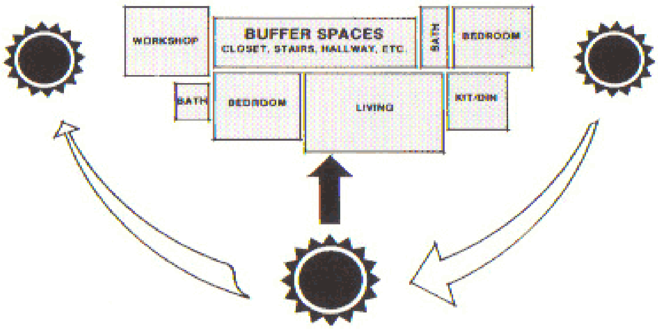

Fig. 4 - Interior space should be arranged so that rooms with high heating and lighting requirements are arrayed along the south wall.

Long east-west plan arrangements increase winter sun-facing skin available to collect radiation. Generally, building oriented along an east-west axis is more efficient for both winter and summer cooling. This orientation allows for maximum solar glazing (windows) to the south for solar capture for heating. This orientation is also advantageous for summer cooling conditions since it minimizes east-west exposure to morning and afternoon summer sun light.

Sunspace

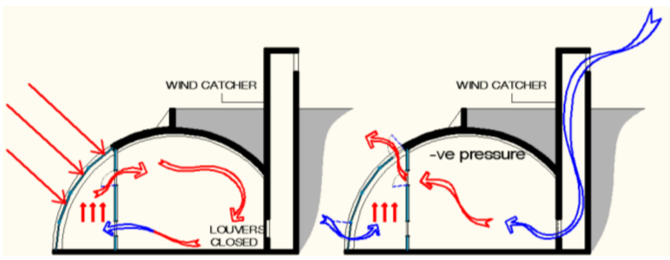

Fig. 5 (left) Schematic section for winters
(Right) Schematic section for summers

Sunspaces can be used to collect the suns heat, store it centrally, and distribute it to other rooms. The wind is preheated in the sunspace before entering the building. A sunspace, unlike direct gain and trombe wall systems, adds a room to the building.

Winter section: Two openings are provided on the wall dividing the sunspace and room. The air in the sunspace rises when heated by radiation, and is drawn inside the room and cool air in the room which is at a lower level is let back in sunspace. This forms a cycle of passive heating air flow.

Summer section: Low inlets and high outlets can be used in a "stack effect" which can be in the form of wind catchers. Since warn air will rise. A wind catcher placed with an opening exposed to the prevailing wind direction forces the air inside and warm air inside the room is drawn out due to negative pressure formed inside the room. Sunspace can be ventilated to the outside to avoid heating.

A properly vented sunspace can function much like a screened-in porch. Operable windows and/or vent openings should be located for effective cross-ventilation and to take advantage of the prevailing summer wind. In addition to sunspace, combining effects of earth berm, rock bed can be added for optimum results.

Earth berm

Earth sheltering is the architectural practice of using earth against building walls for external thermal mass, to reduce heat loss, and to easily maintain a steady indoor air temperature. Earth sheltering reduces heat loss in two ways: - by increasing the resistance to heat flow of the walls, roof, and floor and by reducing the temperature difference between inside and outside. At a depth greater than 2 ft. (0.6m) below the earth’s surface, daily temperature fluctuations are negligible.

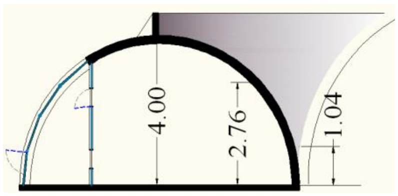

Fig. 6 Schematic section of earth berm

Earth berming calculations:

In a radial path calculation method, the variables consist of the resistivity of the soil, the depth of the wall and the slope of the ground surface. For any given depth X, the effective R is given by:

$ERx = 2\pi (X) (Rsoil) (90-m / 360)$

(Source: ASHRAE)

Where, m is the slope of the ground surface in degrees,

Rsoil is the unit resistance of the soil and

ERx is the Effective Resistance at the depth x.

the Effective R for a depth of 4 M(13.12 Feet), under a horizontal ground surface, is given by substituting X =13.12 and m = 0, so that

ER8 = 2π (3.12) / (90-0/360) Rsoil = 2 X 3.14 X 3.12/ 4 Rsoil
= 20.5 Rsoil

The geometrical component of the heat flow is independent of the soil's thermal properties. For a typical In-situ soil, unit resistance may be assumed to be about R1.25 / foot. Substituting 1.25 for R soil yields a product of ER25.62.

A horizontal strip of wall at 8 feet below grade, therefore, can be regarded as having inherent resistance of R26, without the benefit of any insulating materials.

Rock bed

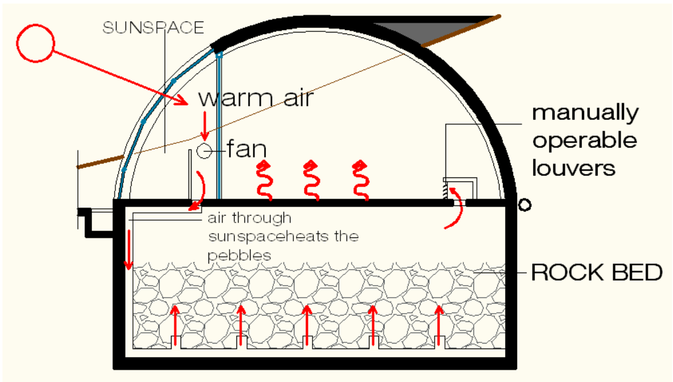

Fig. 7 Schematic section of rock bed

Rock beds are a means of enlarging the thermal mass of the building and thereby increasing the ability to store energy. Air is drawn from the sunspace and through bed of rocks. Heat is given off to the rocks and air is re-circulated to a location in the hot space to collect more heat.

At night when heat is needed, air from the occupied space is drawn through the rock bed, where it picks up heat and distributed back to the occupied space. The rock bed can be located under a concrete slab that will be heated by bed.

Rock bed calculations:

Heat loss calculation: [6]

The purpose of this calculation is for the design of a heating installation. Heat loss rate for a condition which is the coldest for 90% of the time is calculated. The heating installation is then designed to produce heat at the same rate.

Solar thermal quantity available:-

- Average daily radiation on horizontal surface = 5900 W/M²
- Average yearly available = 5900 X 365 = 21, 53,400 W/M²
- Thermal collection at 40% efficiency of collector = 8,61,400 W/M²
- Thermal capacity of rock:-
- Density of rock = 1800 Kg/M²
- Specific heat of rock = 0.22 Kcal/Kg/deg C
- Thermal capacity of rock = 1800 X 0.22
  = 400 Kcal/M³/deg C
- Temperature range = 20°C
- Each M² of rock will store = 465 X 20
  = 9300 W/M depth.

Solution:

Temperature difference Δt = 24^0 c – (2^0 c) = 22 deg c.

Night heat loss through structure (winter):-

Conduction: [6]

Conduction heat flow rate through a wall of given area can be described by the equation:

qc = a x u x Δt

A) Conduction through glazing

Qc = a x u x Δt

= 175m^2 x 2.72w/m^2 /deg c x 22deg c

qc = 10472.8 w

B) Conduction through bermed wall-

Qc = a x u x Δt

= 200m^2 x 0.048w/m^2 /deg c x 22deg c

qc = 212 w

C) Conduction through exposed concrete

Qc = a x u x Δt

= 75m2 x 5.78w/m^2 /deg c x 22deg c = 9537 w

Total qc= 20,221 w.

Convection: [6]

Convection heat flow rate between the interior of the building and the open air depends on the rate of ventilation, i.e. Air exchange.

This may be un intentioned air infiltration or may be deliberate ventilation, which can be given in m^3 / s.

The rate of ventilation heat flow rate is described by the equation:

Qv = 1300 x v x Δt

Where,

qv = ventilation heat flow rate, in w

1300 = volumetric specific heat of air, in j / m^3 deg c

v = ventilation rate in m^3 / s

Δt= temp. Difference, in deg c

If number of air changes per hour (n) is given, the ventilation rate can be found as:

v = n x room volume / 3600

Qv = 1300 x V x ΔT

V = 3 X 1987/3600 = 1.66 M^3/S

Qv = 1300 x V x ΔT = 1300 X 1.66 X 22

Qv = 47476 W

Radiation through glazing: [6]

The rate of heat flow through glazing is described by the equation:

Qs = A x u x ΔT

Where,

A = area of window, in M^2

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u = u-value of glass

Qs = A x u x ΔT

ΔT= (24-2)/2 = 11

= 30 x 4.48 x 11

Qs = 1493 W

Qs = A x u x ΔT(sunspace)

ΔT= (11-2)/2 = 9

= 300 x 4.48 x 9

= 12096W

The thermal balance equation is: Qi – Qc – Qv + Qm = 0

Qm = 10,28,21,760 W

Mass of rock required :-

10,28,21,760/9300= 11056 M^3

Area of building = 450 sq. M.

Depth of rock req. = 2.4m

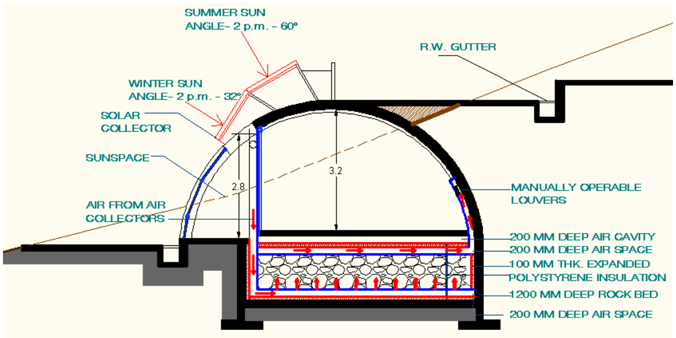

Fig. 8 Schematic design section of rock bed

Building component scale:

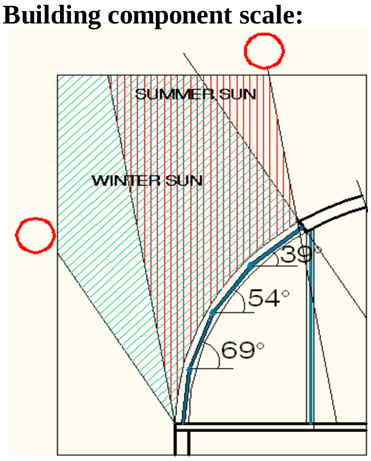

Fig.9 Glazing on south side

Windows and glass type for winter solar gain

In passively solar-heated buildings, low U-factors are important in reduces winter heat loss from large solar collecting glazing areas and in retaining heat collected during the day for use at night.

Entry ways (air lock)

To reduce both direct and infiltration losses, entryways should be recessed or protected against the direct force of prevailing winds. Additional loss reduction can be accomplished by providing an enclosed interior "air lock" space between an entrance door and the main building. It also reduces the amount of cold or warm air entering the living space when the interior door is opened.

Conclusion

The idea of passive solar heating is simple, but applying it effectively requires attention to the details of strategic design, analytic techniques and method of construction.

Modest levels of passive solar heating, also called sun tempering, can reduce building auxiliary heating requirements from 5% to 25% at little or no incremental first cost and should be implemented for all small buildings in cold and cloudy climates. More aggressive passive solar heated buildings designed by using combined passive strategies can reduce heating energy use by from 25 to 75% compared to a typical structure while remaining cost-effective on a life-cycle basis. This approach should be considered for many small buildings in cold and cloudy climates.

References

1. Climatic Design: Energy-efficient Building Principles and Practices, McGraw-Hill, New York, 1983. [697.9 W3]
2. AZSC solar center
3. Arens et al, p. 1202, Olgyay, p. 19
4. Climate Responsive Architecture – Editors – Arvind Krishan et al, Tata McGraw-Hill Publishing Company Ltd, New Delhi, 2001.
5. Sun, Wind and Light – G.Z.Brown, Mark DeKay, Second Edition, John Wiley & sons, New York, 2001
6. Manual of Tropical Housing & Building – O.H.Koenigsberger et al, Orient Longman ltd, India, 1975
7. Climatological & Solar Data for India, T.N.Sheshadri et al, CBRI, Sarita Prakashan.
8. Inside out – G.Z. Brown.
9. MEEB
10. Heating Cooling Lighting – Lencher
11. ASHRAE fundamentals, ASHRAE Inc., Atlanta, 1997.
12. Brown G.Z., DeKay M., Sun, wind and light-architectural design strategies, 2^{nd} Ed., John Wiley and Sons Inc., New York, 2001.
13. Seshadri T.N., Rao K.R.., Sharma M.R., Sarma G.N. and Ali S., Climatological and solar data for India, CBRI, Sariita Prakashan, Meerut, 1968.
14. Climatic Design of Buildings - An Overview http://arch.hku.hk/~cmhui/teach/651567.htm