BRITA in PuBs

Passive Solar Heating

EU framework programme

eco buildings

Guidelines

2007

1 Introduction

Passive solar heating of buildings occurs when sunlight passes through a glazing element, hits an object, is absorbed and converted to heat. Once the heat is in, a well insulated and air-tight building envelope helps prevent heat loss.

Passive solar heating can significantly improve building energy performance as well as comfort levels at low additional costs. But there are problems to address. Even in the Northern countries, the prevention of overheating in the sun-space presents one of the biggest challenges. A helpful technique to control overheating and extend warm conditions in the sun-space once the sun is down, is the use of heavy mass materials in the walls and floors. Thermal mass will absorb solar radiation, smooth out the peaks of solar gain, and slowly radiate heat back into the room when the sun is gone.

Figure 1: Isolated solar gains. Refurbishment of Grong School and Community house in Norway. New solar space added to an old building. Letnes Architects AS.

Passive solar heating is known as space conditioning systems that are driven primarily by natural phenomena and not by power driven mechanical devices.

2 Requirements in regulations

Requirements in many countries, regarding energy use in buildings, are given in technical regulations connected to the statutory building regulations. Old requirements focus on thermal insulation and heat losses. In spite of the building codes increasing requirements to better thermal insulation, in northern countries, the energy consumption in new buildings is rather higher than in older ones. Most likely the reason is higher comfort levels resulting in increased energy use for ventilation, cooling and heating. More equipment is also a contributing factor.

EU countries will successively implement *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*. According to this EU Directive a building's calculated energy demand shall be related to an energy frame. Energy frames are flexible regarding building design and measurements as long as the energy efficiency is satisfactory. [3]

2.1 New regulations require lower energy demand

The new building energy performance directive and the new building regulations will lead to buildings with lower energy use. Intensified requirements will be an efficient policy instrument to decrease energy consumption in new buildings plus in existing buildings which are going to be renovated. It will be necessary to take into consideration all energy use in the operation of the building, i.e. energy for heating, ventilation, hot tap water, fans, pumps, lighting, equipment and possibly cooling.

Thermal insulation, building shape and glazing are crucial to heating needs. A large amount of glazing will still be possible, but holistic analysis of the building's thermal balance should be emphasised. Façades with good design will be necessary to avoid high energy demand.

3 Current practise

Where heating is the dominant requirement, designers do emphasize:

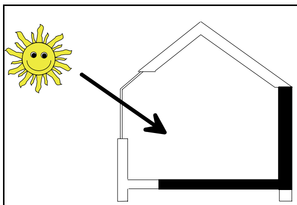
- Insulation of building envelope
- Control of ventilation and infiltration
- Buffer spaces on northern or wind exposed facades
- Entrance doors located away from prevailing winds and from corners, and placed in windbreaks or draught lobbies

Where passive solar heating is desirable, the following design strategies might be implemented:

- Design for maximising solar gain
- Thermal mass to store heat produced by solar gain and to release it as interior temperatures fall
- Unheated conservatories or sunspaces on the south facades. Secondary glazing can create small sunspaces, which, in addition to providing space heating, also can preheat ventilation air and reduce transmission of external noise
- Atria and sunspaces can act as thermal buffer space and also bring daylight into deep building plans

3.1 Passive Solar Heating Strategies

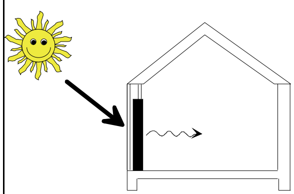
Direct solar gains can be utilized for space heating by letting solar radiation in through windows. The possibilities for utilizing direct solar gains depend on the design of the building. A major prerequisite for exploitation of solar energy in buildings in Europe is that a large part of the building façades or the roof faces south. The most efficient window orientation for heat gain is due south, but any orientation within 30 degrees of due south is acceptable. The effect falls to 2/3 by turning 90 degrees, i.e. facing east or west. [4]



Possible reduction of space heating demand: 5–15 % (experience data from SINTEF)

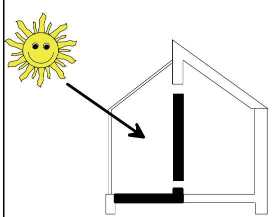
Direct gains
- South facing windows with low U-value and high transmission value
- Interior space itself as "collector"
- Results in temperature fluctuations

Key factors:
- glazing type, glazing size
- amount of thermal mass
- solar control possibilities
- ventilation possibilities



Storage materials: Concrete, brick, adobe (slow heat transfer). Water (high heat capacity, quick heat transfer)

Indirect gains
Solar wall:
- Delays heat transfer to the interior space
- Reduces temperature fluctuations in interior space
- Requires very good glazing
- Limits view out



Possible reduction in energy demand: 20–30 % (experience data from SINTEF)

Isolated gains
- Glazed balcony
- Sunspace
- Atrium

- Primary function: amenity, comfort
- Secondary function: energy savings, buffer effect, preheating

Figure 31: Passive solar heating can substantially reduce the energy demand for space heating. Solar gains must be balanced to cooling demand.

A favourable building shape is two stories facing south and one facing north. Approximately vertical surfaces can utilize the solar gains from the low angle winter sun.

Shadows from other buildings and dense vegetation should be avoided if the goal is to heat the building. However, in summer, vegetation can help to create the necessary shade.

Heavy constructions (thermal mass) can absorb and store some of the heat penetrating windows. Light constructions are able to store less heat than heavy constructions, and the solar radiation may more easily cause overheating.

Passive Solar Heating	Preventing/ reducing heat losses	Thermal insulation
		Super insulated windows
		Air tight building envelope
		Heat recovery
	Exploiting solar energy	Direct solar gains
		Indirect solar gains
		Isolated solar gains
	Modulating/ storing heat gains	Thermal mass

Figure 32: Approaches for heating and thermal sinks.

Building location

Where heating is the dominant need buildings should be situated in the zone that is least shaded during the most important hours of the heating season. South-facing slopes receive more sun than ground sloping north. Taller buildings should be placed to the north, so they do not shade the lower ones. When assessing the potential solar gains, any shade and thermal radiation from adjacent buildings should be taken into account.

Site topography will affect wind speed and direction. In many areas the wind blows predominantly from one direction. When designing buildings, one should attempt to deflect the wind and reduce its speed without reducing solar gains.

Wind speed and direction can be modified by new landforms, structures and vegetation, and the form of individual buildings can be designed to block or divert winds. Using or creating shelter on the site can reduce heat loss from buildings caused by winds, and can also improve the comfort of outdoor living spaces.

Building orientation

The principal façade is ideally oriented south for maximum exploitation of solar energy. South-facing vertical surfaces receive more solar radiation in winter and less in summer when compared with surfaces with east or west orientations. This is approximately in phase with the heating demands.

Direct solar gains
Heavy materials, concrete and stone, give thermal mass which even out temperature swings. Headquarter for E. Pihl & Søn in Lyngby, Denmark. Office building from 1994. KHR AS Architects. (http://www.khras.dk/Projekter/Kronologisk?g=60)

Shading should prevent overheating in the warm season. Windows on east or west facades are often the cause of overheating. They are difficult to shade without blocking out the sun, because of the low angle of the solar radiation. The problem of glare in non domestic buildings can also be a big problem, particularly in winter, because of the low angle of the sun which brings it below any fixed shading device. There also needs to be very effective means to control solar gain to avoid energy use for comfort cooling.

At northern latitudes the advantage of daylight and solar gain through larger windows must be balanced to the heat losses through the windows.

Thermal mass
Thermal mass can store heat produced by solar gain and release it as interior temperatures fall. Thermal mass thus helps to even out interior temperature fluctuation by raising or lowering the radiant temperature of the interior.

The concept of collecting heat through use of external walls for thermal mass is mainly applicable to warmer regions where there is a need for heating, but where thermal insulation is not necessary. In colder regions an uninsulated wall, even south-facing, loses more heat to the outdoor environment than is collected through solar gain. In hot regions, where the heat flow goes in the other direction, it is still better to insulate, in this case to avoid overheating. Therefore external walls should be insulated, which unfortunately prevents penetration of solar heat through the wall. In this case interior walls, floors and ceilings can be used for thermal mass. Mass exposed to direct solar radiation is most effective. Dark colours absorb more energy than light colours. The thickness of the mass is also of importance. In general, mass thicknesses beyond 10–15 cm have little effect. [7]

4 Innovative solutions

Development of strategies, concepts and glazing elements has brought innovation to the field of passive solar heating.

4.1 Strategy to lower energy consumption

«Passive energy design» is a strategy to be used in planning of low energy buildings which are both cost effective, user friendly and robust. The starting point is the reduction of heat loss, and the end point is the choice of energy source. This gives environmental advantages because the focus is placed on energy savings before energy production. [6]

The strategy is based on the Trias Energetica methodology, introduced in 1996 by Novem, the Netherlands and further developed by the Technical University of Delft, the Netherlands.

Further development in Norway has resulted in a strategy with five steps:

1. Reduce heat loss
   Super insulated and air tight building envelope. Efficient heat recovery on ventilation air in heating season.

2. Reduce electricity consumption
   Exploitation of daylight. Energy efficient electric lighting and equipment. Low pressure drops in ventilation air paths.

3. Exploit passive solar energy
   Optimum window orientation. Atria/sunspaces. Proper use of thermal mass. Solar collectors. Solar cells.

4. Control and display energy consumption
   Smart house technologies, i.e. demand control of heating, ventilation, lighting and equipment. User feedback on consumption.

5. Select the most efficient energy sources and carrier
   Use renewable energy sources as much as possible.

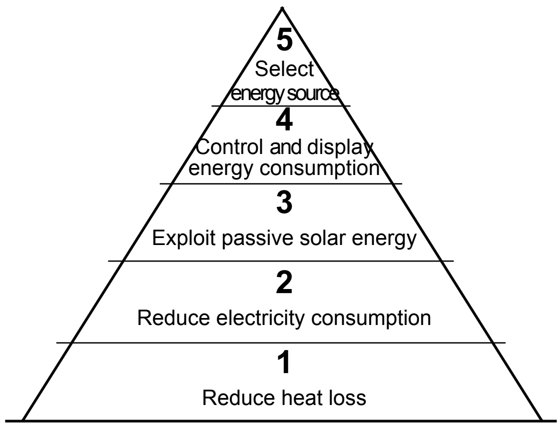


Figure 41: Five steps strategy for energy efficiency

4.2 Solar energy in the Passive House Concept

Various “passive houses”, mostly dwellings, are realised primarily in Germany and Austria. There are also examples of school buildings and offices. Experience indicates that the concept now is so well developed that there are no substantial extra costs to build such houses. But the know-how is still limited to a few enthusiastic experts.

The Passive House Concept is developed in Germany by the Passive House Institute chaired by Dr. Wolfgang Feist. The concept is first of all based on maximum reduction of heat loss, and the remaining heat demand is supplied with a simple and cost effective heating system.

Regarding space heating, the importance of contribution from passive solar heating decreases when the energy demand decreases. In Norway, when it comes to Passive House Standard, the energy demand is so small that the contribution from passive solar heating is almost without significance. On the other hand, regarding domestic hot water, solar energy may give a significant contribution.

The following are the basic features that distinguish passive house construction: [11]

Compact form and good insulation	All components of the building envelope are insulated to achieve a U-value that does not exceed 0.15 W/m²K
Southern orientation and shade considerations	Passive use of solar energy is a significant factor in passive house design in Austria and Germany
Energy efficient window glazing and frames	Windows (glazing and frames, combined) should have U- values not exceeding 0.80 W/m²K, with solar heat gain coefficients around 50 %
Building envelope air-tightness	Air leakage through building envelope must be less than 0.6 times the house volume per hour at 50 Pa ΔP
Passive preheating of fresh air	Fresh air may be brought into the house through underground ducts that exchange heat with the soil. This preheats fresh air to temperatures above 5 °C, even on cold winter days
Highly efficient heat recovery from exhaust air	Most of the heat in the exhaust air is transferred to the incoming fresh air (heat recovery rate over 80 %)
Hot water supply using renewable energy sources	Solar collectors or heat pumps provide energy for hot water
Energy saving household appliances	Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a passive house

Figure 42: The Passive House Concept

4.3 Envelope design

The link between envelope design and building performance is crucial.

Windows

Replacement of traditional windows with new ones that have improved insulation is known as a common and effective way to improve the thermal performance of the building envelope. Low-E glazing improves the balance between transmission losses and solar gains, without significant extra costs.

Today, high performance windows are available in the market; windows with insulated frames, multiple glazing, low-e coatings, insulating glass spacers and inert gas fills, can significantly reduce heat loss compared to yesterday’s windows.

The application of smart windows, such as switchable glazing, spectrally selective glazing and insulating gases (krypton, argon and xenon) are all commercially available. These advanced window technologies can be used in different configurations. [10]

Double-skin façades
The double skin is a system involving the addition of a second, glazed skin installed at a distance from the main façade. The intermediate space that is created provides additional insulation and can be heated by solar radiation. The double skin creates opportunities for maximizing daylight and improving energy performance.

In the summer, the double façade can reduce solar gains as the heat load against the internal skin can be lessened by the ventilated cavity. Shading systems placed within the cavity are protected from the weather. A natural stack effect often develops in a solar heated cavity, as absorbed solar radiation in the glass, the structure and blinds is re-radiated. In the winter, the double façade will act as a buffer zone between the building and the outside; minimizing heat loss, and improving U-values.

In existing buildings double-skin façades can be used to renovate façades that have deteriorated.

Transparent insulation on solid walls
Transparent insulation can also be used in façade renovation. Heat transmission and air infiltration through the building envelope are the major causes of heat loss in old buildings. These losses can be reduced by using improved windows and additional opaque insulation, and by making the building envelope more airtight. While these traditional measures only reduce the heat loss, the use of transparent insulation materials makes it possible both to reduce transmission losses, and to capture solar heat in uninsulated massive walls. The solar heat captured during the daytime is slowly released during the evening.

Transparent insulation is most effective when used on massive uninsulated external walls, constructed of concrete, limestone or brick with few openings. Placed in front of an external wall, the transparent insulation allows solar radiation to pass through, to be absorbed by the wall. The radiation is transformed to heat, which is stored in the wall, and then passively distributed into the building with a time lag.

Figure 43: Indirect solar gains
The walls absorb and store solar heat.
Left: Renovated dwellings in Copenhagen. Dark painted plaster behind transparent insulation covered by glass.
Right: Stone wall behind a layer of glass.

When transparent insulation is applied, together with a transparent cover, it acts as new wall cladding and can thus be used to renovate façades that have deteriorated.

5 Advantages/disadvantages

Passive solar heating can significantly reduce the energy demand for space heating. Passive solutions are more sensitive to the external environment (solar load, temperature, wind, etc.) than conventional mechanical solutions. To utilise the potential of passive solutions with dynamic properties (measures change over time), smart control systems are required. Alternatively, the users can carry out the control, i.e. passive buildings require active users.

6 Costs

Standard building elements can be used in a passive solar heating design. Extra building elements are not necessarily required, just conscious design must be emphasized. In all cases it is recommended to make a better insulated envelope. This is more expensive to build, but savings in energy and other operational costs will largely compensate for this, e.g. by improving the balance between heat gain and heat loss, reducing the size of the heating plant, and cutting fuel bills.

In northern countries there is a significant rise in interest among developers and construction companies with respect to realizing low energy buildings. Buildings with a total energy consumption of less than 50 % of new buildings are being realized. The interest in low energy buildings may be explained by a number of factors, including the prospect of the upcoming energy performance directive, the sudden rise in energy prices, and an increased understanding of the benefits of such buildings.

7 Maintenance and service

Cost-effectiveness, robustness and user-friendliness should be in focus when integrating different passive strategies and technologies into building concepts.

8 Calculation tools

The Transient Energy System Simulation Tool (TRNSYS), commercially available since 1975, is a flexible tool designed to simulate the transient performance of thermal energy systems. TRNSYS is a well respected energy simulation tool under continuous development by an international team.

TRNSYS is most often used by large consultant companies in England and the Netherlands, and by researchers. The tool is complex and time consuming, and smaller companies may find the tool unprofitable. [12]

The Passive House Planning Package (PHPP) is claimed to be a clearly structured design tool that can be used directly by architects and designers.

The PHPP is continuously validated and refined based on measurements. As part of accompanying scientific research studies, measurements from more than 300 projects have so far been compared with calculation results. Of crucial significance was the CEPHEUS project (Cost Efficient Passive Houses as European Standards) within the European Thermie programme. Buildings at 14 different European locations were constructed according to passive house standards.

With few exceptions, every country has their own calculation program. In Norway the program most often used, is called Energi i bygninger 3.5 (Energy in buildings).

There has been an evolution from a purely technical focus on individual technologies and sub-systems towards taking a more integrated approach combining building design and energy technologies also including more "soft issues" like process and social-related issues. A multidisciplinary approach is called for; a context of a whole building analysis, rather than on a component-by-component basis.

9 Reference

9.1 Compilation

This guideline is written as a part of the project Bringing Retrofit Innovation to Application in Public Buildings (acronym: BRITA in PuBs), EU 6th framework programme, Eco-building (TREN/04/FP6EN/S.07.31038/503135). The authors are Karin Buvik from SINTEF Building and Infrastructure, Norway, and Anne Grete Hestnes from the Norwegian University of Science and Technology. The professional editing was closed in May 2007.

9.2 Literature

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[12]The Transient Energy System Simulation Tool, TRNSYS: http://www.trnsys.com/

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