Towards Passive Houses in Cold Climates as in Sweden

Bo Adamson

Division of Energy and Building Design
Department of Architecture and Built Environment
Lund University
Faculty of Engineering LTH, 2011
Report EBD-R--11/35

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 110 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 46 000 students attending 274 degree programmes and 2 000 subject courses offered by 63 departments.

Division of Energy and Building Design

Reducing environmental effects of construction and facility management is a central aim of society. Minimising the energy use is an important aspect of this aim. The division of Energy and Building Design belongs to the department of Architecture and Built Environment at the Lund University, Faculty of Engineering LTH in Sweden. The division has a focus on research in the fields of energy use, passive and active solar design, daylight utilisation and shading of buildings. Effects and requirements of occupants on thermal and visual comfort are an essential part of this work. Energy and Building Design also develops guidelines and methods for the planning process.

Towards Passive Houses in Cold Climates as in Sweden

Bo Adamson

Professor emeritus and former Head of the Department of Building Science at Lund Institute of Technology, Lund University

Layout: Hans Follin, LTH, Lund.

Report No EBD-R--11/35
Towards Passive Houses in Cold Climates as in Sweden. Department of Architecture and Built Environment, Division of Energy and Building Design, Lund University, Lund

ISSN 1651-8128
ISBN 978-91-85147-48-9

Lund University, Lund Institute of Technology
Department of Architecture and Built Environment
Division of Energy and Building Design
P.O. Box 118
SE-221 00 LUND
Sweden

Telephone: +46 46 - 222 73 52
Telefax: +46 46 - 222 47 19
E-mail: ebd@ebd.lth.se
Home page: www.ebd.lth.se

Contents

Foreword

Being in charge of research and education since 1964, the author has some perspective of the development towards more and more energy efficient residential buildings in cold climate. Below, in three sections, the development concerning thermal insulation and the need of ventilation will be briefly discussed and the passive house idea for cold climates elaborated.

Three short papers are presented:

1. Thermal Insulation of Residential Buildings.
   Health, Economy, Energy Conservation and Climate Protection
2. Ventilation (Air Changes and Air Tightness) of Residential Buildings.
   Not less, and not more
3. The Idea of a Passive House in a Cold Climate

It has to be said: *Energy conservation and the passive house concept is one, but important, aspect in the design of a house. The design of the building has to be the best solution with respect to given environmental, functional, technical, aesthetical and economical conditions.* Engineers seem often to over-emphasize technology.

1 Thermal Insulation of Residential Buildings

Health, economy, energy conservation and climate protection

Before World War II residential buildings in Sweden were built with known and tested engineering and heated up with wood, coke or coal. Local building codes prescribed how the buildings should be designed and how an acceptable indoor climate could be achieved. The indoor climate conditions had its basis in prescriptions by the National Board of Health.

The hygienic requirements for indoor comfort were expressed as minimum room air temperatures during day and night, as for example 18°C and 16°C, respectively. Openings for supply of fresh air were also prescribed as well as ventilation ducts up over the roof in order to enable good gravity ventilation. Condensation on inner surfaces of the building envelope indicated bad thermal insulation and/or bad ventilation and was observed by local health supervisors. An air temperature difference between head and foot of more than 3°C was sometimes considered as a result of bad thermal insulation.

The Local Building Codes in cities reflected traditional, tested building engineering, as for example outer walls in multi-storey residential buildings made by solid 1½ brick construction. This means an overall heat transfer coefficient U = about 1.0 kcal/h,m^2,°C (=1.2 W/m^2,K). Windows had to be double-glazed during the heating season. In the beginning of the twentieth century the windows had two casements; one opened to the outside and one to the inside. The latter was applied during the heating season, and often sealed by paper strips in order to avoid condensation on the inner surface of the outer pane. However, the tenants often neglected to apply the inner casements, which resulted in heavy condensation and deterioration of the windows. The coupled double pane window was "invented", i.e. both casements were coupled together and opened to the outside (since 1920) or to the inside (since 1940).

In the architect's design office there was a staff of engineers with long and deep knowledge of traditional building.

The local requirements considered health issues, the well-being of people. A Governmental Study 1943 describes this:

> "Of health reasons one must require that the thermal insulation of a building is so good that people can live and work in the building without feeling discomfort of cold, also at coldest weather conditions, and condensation of moisture on inner surfaces of walls not occurs. Such condensation depends however not solely on bad thermal insulation. A too low ventilation rate also results in a high humidity of the room air, and condensation." (free translation)

1.1 National building codes

A national building ordinance was issued 1947, with the local building codes still valid. Application regulations were issued by the National Board of Public Building as BABS 1946 and BABS 1950. A new national building ordinance was issued 1960, and the local buildings codes were replaced by this ordinance. Application regulations were issued by the National Board of Public Building as BABS 1960, the first national code.

Below the requirements for outer *walls made of brick* shall be examined for Stockholm (temperature zone III).

BABS 1950

In BABS 1950 a highest overall heat transfer coefficient was established for outer walls

Walls made of solid brick with a density above 1.4 kg/dm^3	U = 1.05 $kcal/h,m^2,°C$ [1]
Walls made of solid brick with a density between 1.1 and 1.4 kg/dm^3 or concrete with thermal insulation on the outside	U = 0.95 $kcal/h,m^2,°C$
Other walls of mostly mineral material with a weight ≥ 100 kg/m^2	U = 0.85 $kcal/h,m^2,°C$

[1] 1 $kcal/h,m^2,°C$ = 1,163 $W/m^2,K$

Wall of wood or made of another material,
with a weight below 100 kg/m^2 U = 0.65 kcal/h,m^2,°C

This means that for a wall made of solid brick with a density = 1.8 kg/dm^3, a 450 mm thick brick wall is required (1½ brick of "big brick", 300×145×75 mm). If solid brick with a density = 1.6 kg/m^3 is used, 375 mm of "normal brick" (250×125×65 mm) is enough. This reflects the traditional building practice before the World War II.

During the war, Sweden suffered of lack of coal and coke and made light bricks with a density = 1.2 kg/m^3, which allowed a single brick wall (250 mm), but with a low load bearing capacity. Therefore brick with a high density was used, insulated on the inside with 50-70 mm cement-fixed wood wool board. The latter wall with a 70 mm board arrives at U = 0.68 kcal/h,m^2,°C, a true energy saving wall - both in the construction stage and during the operation of the building. The World War II had exposed that energy supply is a national problem and that new technical solutions can be found, often economical.

BABS 1960 and SBN 1967

Despite the experiences from the World War II, and that the code was nationally adopted, the requirement on thermal insulation of outer walls were not changed very much. For wall of solid brick an overall heat transfer coefficient U = 1.0 kcal/h,m^2,°C was still required. This is remarkable, as 1956 Sweden was hit by the Suez oil crisis with a sharply limited import of oil, but the memory is short.

New materials, new technical design and new construction methods

During the 1950s and 1960s new materials came into practice, as plastic materials, gypsum wallboard, aerated concrete and new mineral wool products. This gave place for new technical design solutions. In the middle of the 1960s the Swedish Government launched a "million program"; one million apartments should be built in ten years. This required a doubled material production and new construction methods. The program was enabled as the non-profit-making housing companies, mostly municipally owned, could get favourable governmental loans practically up to the production costs. The oil price was low and energy saving was not an issue.

Many new materials and design methods came into practice. Without sufficient knowledge in building physics, without testing and without experience-feed-back many of these houses have suffered of moisture problems and required rebuilding.

Building Codes SBN 1975, SBN 1980 and NR 1988

The oil crisis 1973-74, and more crises later on, exhibited how dependent Sweden is on oil supply from abroad. The high oil prices stroke the trade balance and the supply was not secured. It was a truly national problem, which also was reflected in the Building Code SBN1975, Supplement 1 Energihushållning (Energy Conservation).

Outer walls:	U = 0.30 W/m^2,K
Roof or attic ceiling:	U = 0.20 W/m^2,K
Floor facing outdoor air:	U = 0.20 W/m^2,K
Windows (glazed part):	U = 2.00 W/m^2,K (i.e 3 panes)

It was a national interest to reduce the energy use for space heating, and for the first time the expression "energihushållning", energy conservation appeared in the Code. The requirements were maintained in the Code SBN 1980.

A new law was issued 1987 and the new authority "Boverket", (the Swedish Board of Housing, Building and Planning) issued new building regulations, NR 1988. In these one had deviated from design rules specifically for outer walls, roofs, windows etc, and instead stipulated a highest average overall heat transfer coefficient for the entire building envelope. It is of interest to observe that it was allowed to reduce the U-values for the glazed parts, depending on orientation and shading. In other parts design requirements have in principle been replaced by functional requirements, giving liberty of choice to the architect and engineer. The Government, consequently, handed over the responsibility of design and construction to the market, which according to the author is doubtful. The responsible part can go bankrupt and leave the house owner with the bill of reconstruction.

Housing policy through subsidized loans and design requirements

The housing policy during 1945 to 1990 has mostly been formed by the social democratic party and put into practice by subsidised loans linked to design requirements, and long-term building economy could thus be given priority. Inrease of thermal insulation above Building Code requirements was economically possible by subsidised loans, within given limits, and changed from time to time. However, the developers gave mostly priority to low investment costs and kept the designs close to building code requirements.

1.2 Thermal Insulation – A Safe Method to Save Energy?

Thermal insulation can be regarded as a safe method to save energy. The indoor health issues are improved, it is economically motivated and reduces the need of energy. But there is a problem: "Invented" new designs look possibly very satisfactory on the drawing board, but the use in full-scale production without a previous testing period, and without experiences is risky. The traditional building methods before the World War II were well known – by everybody; architects, engineers, workers and house owners. Few of the designs, used since the 1960s in Sweden can be regarded sufficiently studied before they were used in a full-scale production. Possibly, this is a too severe statement, but a lot of moisture damages indicate that it is not far from the truth.

1.3 Summary

Before the World War II, thermal insulation was a question of health. The traditional housing design was regarded to create an acceptable indoor climate, if a given minimum indoor air temperature was maintained. The Building Codes before the oil crisis 1973-74 allowed, compared with today's standard, a poor thermal insulation. The oil crisis indicated that a safe supply and the cost of imported fuel is of *national* interest. The national Building Codes 1975 and 1980 reflected this and required much better thermal insulation of the building envelope. During the last decade the national interest to reduce the CO_2-emissions to the atmosphere by burning fossil fuel has been the main argument to save energy, but the saving methods are the same as before.

2 Ventilation (Air Changes and Air Tightness) in Residential Buildings

Not less, and not more

2.1 The Swedish building codes

The development of the ventilation requirements for residential buildings is shortly described below.

The Swedish building code 1960

Previous to the World War II, local building codes regulated the residential buildings and these codes were in force until 1967, when a national code replaced them. The local codes presumed traditional natural (gravity) ventilation and prescribed openings for outdoor air supply and ventilation ducts up over the roof. In the national recommendations BABS 1960 it was said that ventilation in residential building can take place either with natural (gravity) ventilation or mechanical ventilation. For natural ventilation the requirements were practically the same as in the local codes.

For mechanical ventilation of residential buildings, it was required:

Rooms over 8 m^2:	25 m^3/h
Kitchen:	80 m^3/h
Bath:	60 m^3/h

For a three room apartment this gives 215 m^3/h, or (with 75 m^2 apartment area and 2.5 m room height) 1.1 air changes per hour. During the 1960s measurements with tracer gases gave 0.7-0.9 ach. When we measured the natural ventilation in the 1980s in China, we arrived at ≥ 2 ach, but in this case the windows were extremely leaky.

The building code 1967

The Building Code 1967 allowed natural (gravity) ventilation of all residential buildings and gave requirements of supply air and ventilation ducts.

For mechanical ventilation (extract systems and balance systems) the minimum ventilation rate was

$$q = 2.2 - 0.004G \qquad m^3/m^2,h$$

where G is the area of the apartment in m2. With a room height = 2.5 m, the air changes arrive at

0.76 ach for G = 75 m²
0.66 ach for G = 140 m²

Obviously, an air change equal to 0.7 ach is regarded as a minimum hygienic requirement. Most of the multi-family houses, built in the late 1960s and early 1970s had mechanical ventilation.

The building codes 1975 and 1980

These codes were issued after the oil crisis 1973-74 and reflect a national conviction of energy conservation.

During the preparation of the code it was discussed to require a very good air tightness of the buildings and balanced ventilation with heat exchangers. The responsible minister hesitated however, because she suspected advantages for the manufacturing industry. The requirement of supply air was instead reduced to 0.35 litre per second and m^2 floor area. This means, with 2.5 m room height, 0.5 air changes per hour. As I remember there was no hygienic research at hand for this decision. Such a decision needs good knowledge of emission from building materials and people's living, as well as limitation values for these emissions. Moreover, people's discomfort is difficult to measure and may be related to many parameters. As an example: Research with school teachers regarding the experience of dry room air showed little correlation to the air's relative humidity, but a strong correlation to the room air temperature. Cold air is also experienced as fresh air.

The result was that natural (gravity) ventilation was allowed in one-family buildings, but for multi-family buildings mechanical ventilation with given lowest air flow of supply or exhaust air (= 0.35 l/s per m^2 floor area), was prescribed. This gives an air change of about 0.5 ach. It was pointed out that natural ventilation not always, under all weather conditions, could fulfil the desired number of air changes, and that high content of radon must be taken in consideration.

A required air tightness of building components had been given already in the Supplement to Building Code 1975, as a highest acceptable air leakage (m^3/m^2,h) at a given pressure difference in Pa. The area refers to the building envelope area. Thus for outer walls it was, at 50 Pa pressure difference, required less leakage than 0.4 m^3/m^2,h for 1-2 storey buildings and 0.2 m^3/m^2,h for higher buildings.

In the Code 1980 a highest air leakage of the whole building was introduced as the number of air changes per hour (ach/h) when the building (apartment) was exposed to 50 Pa pressure difference. This requirement is easy to verify by tracer gas measurements. Somewhat simplified it was required a maximum of 3.0 ach/h for 1-2 storey buildings and 1.0 ach/h for higher buildings.

2.2 "Houses must breathe"

Already when the requirement of air tightness of building components was introduced 1975, voices were raised by "back-to-nature-people", saying "Houses must breathe". This movement was strengthened when the requirement of air tightness of the whole building was introduced 1980. In addition many people complained about bad air in their gravity ventilated houses. Hearings were held in the Government Office, it was a big issue, also politically. The responsible Nordic authorities (Nordic Committee for Building Codes) agreed on a minimum requirement of 0.5 air changes per hour for residential buildings[2].

[2] Jan Sundelin: Guidlines for Nordic Regulations Regarding Indoor Air Quality (Environment International Vol 8 pp 17-20 1982).

2.3 Reflection

The national building codes gave instructions how to design the building from a technical point of view. A desire to diverge from the codes gave a burden of proof. Local building authorities checked that the codes were fulfilled. In last decades the building sector has been given the responsibility and the local building authorities are given a more passive role. This is in the author's opinion a mistake. Competence is not in place in all parts of the building sector.

But, how about the ventilation rate of 0.5 ach? Since the scientific foundation still is not complete, and if anyone would like to propose a decrease of the ventilation rate, the burden of proof is in the hand of the proposing party. In any case, more research has to be carried out regarding ventilation rates, indoor air quality and health issues.

3 The Idea of a Passive House in a Cold Climate

The first passive houses were shelters without any heating. But people discovered that a fire in the shelter improved the “indoor” climate, and the shelter became an active house.

In the 20th century the buildings were designed to have a better indoor climate, but to the cost of higher yearly heat requirement. The energy was cheap until 1956, when the Suez crisis temporarily increased the oil prices and 1973-80, when OPEC increased the oil prices dramatically and permanently. Energy conservation became the key issue.

Passive houses, i.e. houses without any additional heating were used in USA in locations with a lot of solar radiation and solar heat gain was an essential part of the heat supply – above the heat generated by people, and electrical appliances. In those houses people were prepared, occasionally, to accept low indoor temperatures during cold winter periods.

3.1 The idea to exchange costs for heating and ventilation into increased cost for the building envelope

For the author the idea to partly replace the costs for the heating system with an improvement of the building envelope aroused 1962. As consultant and designing housing areas with mostly single family houses, I made myself the question, if it was possible to use electricity for space heating. At that time, however, oil was cheap and electricity expensive. Calculated in heat after conversion the electricity was 3-4 times more expensive than oil. I got the idea to calculate the investment cost for *both* a house with direct electrical heating and electrical hot water production *and* for an oil heated house with panel radiators, feed water system, chimney, and hot water production. The latter was more expensive and the difference was astonishing high. I got an amount of money to improve the building envelope with better thermal insulation and better windows with three panes. By balancing the total costs for the two systems I could determine which electricity price I could pay:

$$B_e + H_e + PVC\ (p_e \cdot W_e) = B_o + H_o + PVC\ (p_o \cdot W_o)$$

where

B = Building envelope investment
H = Heating system investment
PVC = present value coefficient
p = heating price after conversion from oil or electricity
W = yearly heat requirement
$_e$ = electricity
$_o$ = oil

To the right side of the balance, the present value of additional repairing and maintenance costs for the oil heating system compared with the electricity system can be added. The price of electricity can be optimized by calculating different levels of energy saving measures.

The calculation displayed that it was possible to pay the actual electricity price, and a group of 32 houses in Skellefteå, in the North part of Sweden, were built. Measurements confirmed the calculations.

3.2 Passive heating of residential houses in Beijing – a feasibility study

The department for Building Science had during the 1980s and beginning of the 1990s a cooperation with The Ministry of Construction concerning "Design of Energy Efficient Houses in People's Republic of China including Utilization of Passive Solar Energy". Within that project a feasibility study of passive houses in Beijing was carried out . The idea was to take away the heating system in multi-storey residential building and use the money to improve the building envelope. The study was based on detailed computer simulations of the heat balance of a building with various degree of thermal insulation and solar heat gain.

[3] Adamson, Bo: Design of Energy Efficient Houses in People's Republic of China including Utilization of Passive Solar Energy. 6: Passive Heating of Residential Houses in Beijing – a Feasibility Study. (Report BKL 1989:4 (E), Department of Building Science, Lund Institute of Technology, Lund University, Sweden).

3.3 Heated residential buildings

New multi-storey residential buildings in Beijing were in the 1980s built with 375 mm solid brick in outer walls (U=1.36 W/°C,m^2), the floor between storeys was made of 120 mm hollow concrete slabs and the roof of 120 mm hollow concrete slabs + a ventilated space + thin concrete slabs forming the roof surface (U=1.2 W/°C,m^2). Windows were single glazed with steel frames and the ventilation rate was assumed to 1.1 air changes per hour in the apartments. This figure is low in comparison with measurements, indicating more than 2 ach - but possible to reach by a suitable weather stripping of the used windows. In Beijing the heating season was by law limited to Nov.15 – Mar.15. For middle apartments the annual heat requirement[4] was calculated to 77 kWh/m^2 apartment area, the annual minimum indoor temperature was calculated to 9°C and with 200 hours during the year below 14°C and 500 hours below 16°C. All these temperatures, below 18°C, were obtained outside the heating season. These low temperatures can be verified by everyone that visited Beijing in the 1980s in the beginning of November. During the heating season the indoor temperature was set to 18°C.

Without limitation of the heating season the annual heating requirement was increased to 83 kWh/m^2 (apartment area) and the indoor temperature was then always equal or above 18°C.

If the indoor temperature set point during the heating season was decreased to 16°C the annual heat requirement was reduced to 67 kWh/m^2 (apartment area).

Increased thermal insulation and large windows facing south

The winter climate in Beijing and northern China is influenced by a high pressure over Siberia. Cold winds are blowing from the north but the sky is clear with a lot of solar radiation, which can be used for space heating. Large glazed areas facing south is a good heating strategy - and of course thermal insulation of the building envelope together with limitation of the ventilation rate, which often is too high because of a leaky envelope.

[4] All annual heat requirements concern heat supplied to the apartments.

A case (D) with

- outer walls of 240 mm brick + 50 mm thick slabs of cement-fixed wood-wool on the inside (U=0.87 W/°C,m^2),
- a roof with 100mm mineral wool between the concrete slab and the thin concrete slabs forming the roof surface (U=0.31 W/°C,m^2),
- large double glazed windows (10.5 m^2 glass area) facing south and
- weather stripping of windows, resulting in 1.1 air changes per hour in the apartment.

was calculated. The annual space heating demand was reduced to 40 kWh/m^2 apartment area and the annual minimum indoor temperature (outside the heating season) increased to 13°C. This case could be achieved with, at that time, available technology.

Another case (E) with:

- outer walls - equal to the case above
- a roof - equal to the case above,
- large very good double glazed wooden windows (10.5 m^2 glass area) facing south and
- a *reduced ventilation* rate = 0.5 air changes per hour in the apartment, as a result of the better windows (Swedish standard from the 1950s). This ventilation rate is enough for a good hygienic standard according to Swedish experiences.

The annual heat requirement was reduced dramatically, to 14 kWh/m^2 apartment area, mainly because of the better air tight wooden windows. The annual minimum indoor temperature (outside the heating season) was 16.5°C.

A further case (H) with

- outer walls of 240 mm brick + 100 mm mineral wool boards on the inside (U=0.33 W/°C,m^2),
- a roof with 200 mm mineral wool between the concrete slab and the thin concrete slabs forming the roof surface (U=0.18 W/°C,m^2),
- large triple glazed wooden windows (10.5 m^2 glass area) facing south and
- air tight building envelope, with good windows arriving at 0.5 air changes in the apartments, enough for a good hygienic standard,

arrived at an annual heat requirement = *4 kWh/m^2* apartment area and an annual minimum indoor temperature = 18°C, all over the year.

A final case (I) with quadruple glazed windows instead of triple glazed gave an annual heat requirement = 3 kWh/m^2 apartment area.

3.4 Passive residential buildings

The same buildings were simulated without any auxiliary space heating apart from the heat from people and appliances, i. e. real passive buildings.

Case D (see above) without heating arrived in the following minimum indoor tempera-tures:

- Annual minimum indoor temperature: 3°C
- Below this indoor temperature during 100 hours per year: 5°C
- Below this indoor temperature during 200 hours per year: 6°C
- Below this indoor temperature during 500 hours per year: 7°C

These temperatures were considered totally unacceptable, although they are common in the non-heating zone in China, approximately south of the Yangtze River. As seen below, the indoor temperature can in this part of the country go down to 3-4°C. It is possible to live in such low temperatures with very heavy clothing – see below.

Case E arrives at:

- Annual minimum indoor temperature: 7°C
- Below this indoor temperature during 100 hours per year: 9°C
- Below this indoor temperature during 200 hours per year: 10°C
- Below this indoor temperature during 500 hours per year: 12°C

with reasonably better indoor temperatures.

Case H is even better:

- Annual minimum indoor temperature: 10°C
- Below this indoor temperature during 100 hours per year: 13°C
- Below this indoor temperature during 200 hours per year: 14°C
- Below this indoor temperature during 500 hours per year: 16°C

And case I, slightly better:

- Annual minimum indoor temperature: 11°C
- Below this indoor temperature during 100 hours per year: 14°C
- Below this indoor temperature during 200 hours per year: 15°C
- Below this indoor temperature during 500 hours per year: 16°C

The low indoor temperatures occurred mainly during nights and it was proposed that case H should be used as a basis for the design of a passive multi-storey residential house in Beijing. The total cost was assumed to be slightly above the current design, when applied in large series.

Our Chinese counterpart told us that it was not possible to convince the Beijing authorities to design and build such a building. The technology was not commonly known, import of material was necessary and temperatures below 18°C was not acceptable during the normal heating season.

In these days the situation is different, technology transfer is part of the market economy in China and energy conservation and air pollution is high on the agenda.

3.5 Comfort considerations at low indoor temperatures

In passive residential buildings the indoor winter climate can be very cold. Experiences from the non-heating zone in China indicates indoor temperatures, which are only a few degrees above zero during cold winter days. The clothing is of cause adapted to the low temperatures and Markus and Morris give the following clothing values:

1.0 clo = European typical business suit (+ cotton underwear, long-sleeved shirt, tie, woollen socks, shoes)

1.5 clo = European heavy three-piece business suit (+ long cotton underwear, long-sleeved shirt, tie, woollen socks, shoes)

2.0 clo = Heavy suit with one or two layers of long wool underwear, pullover

Using graphs in Markus and Morris[5] the following discomfort values on the cold side, DISC(-) can be calculated (DISC -3 = Cold, DISC -2 = Cool and DISC -1 = Slightly cool).

[5] Markus, T.A. and Morris, E.N.: Buildings, Climate and Energy (Pitman Publishing Ltd, London 1980).

Clothing: 1.0 clo (European winter business suit), relative humidity = 50%, activity=1 met (resting).

Air velocity (m/s)	Operative temperature (°C) for DISC=-0.5	DISC=-1.0	DISC=-2.0
0.1	18	15.5	10
0.5	21	17	13

Clothing: 1.5 clo (heavy European business suit), relative humidity = 50%, activity=1 met (resting).

Air velocity (m/s)	Operative temperature (°C) for DISC=-0.5	DISC=-1.0	DISC=-2.0
0.1	14	11	5
0.5	18	14	9

Clothing: 2.0 clo (heavy suit with a lot of woollen underwear), relative humidity =50%, activity=1 met (resting).

Air velocity (m/s)	Operative temperature (°C) for DISC=-0.5	DISC=-1.0	DISC=-2.0
0.1	10	7	0
0.5	13	9	4

It is remarkable, that it is possible to stand temperatures around zero degrees with a discomfort not more than DISC=-2.0 (cool) if properly clothed. In heated buildings, especially in western countries, temperatures below +18°C are regarded as uncomfortable.

3.6 Improved indoor climate in the non-heating zone in China

In Wuxi, between Shanghai and Nanking, a six storey residential building in the design state was offered as an experimental building for improved indoor climate by better thermal insulation. Based on normal design standard the indoor temperature was calculated and to our surprise the annual minimum temperature arrived at +4°C. Presented at a seminar in Shanghai, many in the audience told us that it can be below zero. We were given 8% of the calculated building cost to improve the building envelope. The outer walls were given an extra insulation with a locally produced insulation board, the roof was provided with loose insulation in bags and the windows were carefully weather stripped. The annual minimum indoor temperature was calculated to 10-11°C. Measurement later on verified the calculations.

People were very happy with the improved indoor climate and the local authorities were asked to build more houses of the same kind.

3.7 Two passive house concepts

Passive house design has developed along two different lines:

- Design and living in accordance with nature
- Design and living using technology

Design and living in accordance with nature

In climates with a high amount of solar radiation, as for example the climate in Arizona and New Mexico in USA, the passive concept of housing has been used since long. The idea was to use solar heat gain as the main heating source for the building. But the heat has to be stored from day to night and therefore the buildings were designed with outer and inner walls made by stone materials. Many of these houses are beautiful and based on ideas from traditional architecture. New ideas as solar walls for heating of the room air, big water tubes inside glazed areas and bottle walls with bottle bottoms forming the outside of the wall and the bottle necks forming the inside with good heat transfer from the solar heated water-filled bottles to the room air, were used. But in all cases they were passive houses using the natural means for space heating. Those houses need however families who are interested and addicted to *live with nature* and willing to stand low indoor temperatures during periods with cold winds and little sun by a suitable clothing – as people in the non-heating zone in China. Normally the American passive houses have some open fire place, also in accordance with traditional architecture.

But a house has normally to serve more than one family, and the next family can be less interested to live with varying temperatures indoors, sometimes low. They want to have a high indoor temperature and must provide the house with more heat, possibly by direct electrical heating. Experiences from our Chinese research in cold climate (Beijing) and research in hot and arid climate (Sahara) has taught us that a good "passive design" is a good basis even for a house with auxiliary heating or cooing.

Design and living using technology

Since the oil (price) crises in the 1970s countries with cold climate have, more or less, promoted energy saving measured by better thermal insulation, utilizing solar energy, energy saving appliances and heat recovery. Today, single-family houses in Sweden usually have 250 mm mineral wool in outer walls, 400 mm in roof, windows with U = 1.2 W/m^2,°C and heat recovery on ventilation air are often used. Heat pumps have captured a big market.

However, some new wall and roof designs have caused problems - mostly moisture problems, and heat pumps and heat exchangers have had operational problems and are not as efficient as advertised. Pumps and fans require a lot of energy for operation; at least if not the best products are chosen. New technology causes problems when it is implemented in a large scale. We had the experience in the 1960s in Sweden, when the production of residential houses was more than doubled during a ten year period. All of the designing architects and engineers had not the necessary knowledge to design the buildings, all the contractors and workers had not the knowledge to produce in accordance with the proposed design, and the control from authorities was not sufficient. The same happened - and happens - with the new energy-efficient design.

It takes weeks to design a house, but it takes years to get it to operate in accordance with the design.

Today the passive house concept in Germany, Austria, Sweden etc. is that a passive house should only use an very little amount of energy for heating expressed in a number of kWh per m^2 living area per year. Engineers love to reach a low figure for heat requirement or air leakage of the house or for something else and they are proud when the indoor temperature can be held within narrow limits. But a residential house is not an energy saving system, it is a place for living. A good design shall meet aesthetical, functional, technical, economical, personal and national requirements to be the best solution. But today, some solutions seems to be “Christmas trees for engineers” with extreme thermal insulation, heat exchangers for ventilation air and waste water, heat pumps, solar collectors, accumulators etc, etc..

Which concept?

My personal opinion, based on many years experience, is that new technologies require *many* years experience in order to be common *knowledge* for designers and builders - and authorities.

Mechanical and electronic equipments have shorter life time than building materials. In addition such equipments often have unexpected and higher operation and maintenance costs. House owners have little knowledge of the system and the owner has little possibility to evaluate the operation. The proposed systems must be fool-proved, not requiring extensive instruction or good technical knowledge. Today's cars are good examples. The driver needs no technical knowledge to use the car. The subsystems of the car are plug-in-systems, where a module is exchanged, when not working properly.

An energy efficient building envelope requires, if properly designed and built, less maintenance and need no replacement during the life-time of the building.

People in industrialized countries are used to have a high indoor temperature during winters, in Sweden 22-24°C. They will not accept lower temperatures. The technological approach has to consider this.

Personally I have my heart in design and living with nature but my experience tells me that design and living with technology is the practical solution.

But remember: The design should meet aesthetical, functional, technical, economical and national considerations. Not only be a technical solution of an energy saving problem.

LUND UNIVERSITY

ISSN 1671-8128
ISBN 978-91-85147-48-9