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Passive Houses in a Cold Climate

by

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Abstract

The Passive House Standard, green and sustainable buildings, which have a descent history as well as being currently developed, will play a key role to reduce or slow down the development of global warming. My main focus in this thesis is on Passive Houses and the problems following when constructing in cold climates and if it is possible to expand the Passive House market to more extreme climates than exist in central Europe. The conclusion made here is that it is achievable to reach the Passive House Standard in a cold climate, especially when taking location, orientation, windows area, insulation and the heat recovery of the ventilation system into consideration from the very start of each project. In an even harsher climate a special addition to the Passive House, a stove, could help to come close to its standard. Even though the actual Passive House Standard will be hard to achieve and most likely quite costly, a building close to this standard will still have its benefits for the residents of the house as well as the environment and that should be the focus for the future.

Acknowledgements

I would like to thank my adviser and teacher Robert C. Miller for helpful comments during the process of this thesis. I would also like to thank my fiancée Linda Hrönn Björgvinsdóttir for faking a genuine interest in Passive Houses and for making this report grammatically correct.

Table of Contents

Introduction

The Passive House concept is a very large subject which can be broken down into many different parts where each part can be investigated more extensively, as the different designs, the location (climate), the economy, the construction principles, the indoor climate, the passive solar energy and many more. On each of these different issues books have been written in almost countless numbers. Passive Houses are quite common in Austria and Germany while other countries are still trying to figure out if and how it is possible to achieve a Passive House in certain weather and climate conditions. Another back holder is the building tradition in some countries, for example in Denmark with the wanted brick facade. I recently read in a newly published article[1] that overheating is a huge problem in many Passive House constructions here in Denmark, though the climate is quite similar to central Europe. If the Passive House Standard could be adapted to all new-and refurbishment projects in all climate zones it would have a great impact on energy usage and CO_2 emission of buildings and in times with rising energy cost and global warming the Passive House Standard could help to solve or at least reduce these problems.

My main focus in this dissertation is on Passive Houses and the problems following when building in cold climates and if it is possible to expand the Passive House marked to more extreme climates than exist in central Europe. I have a personal interest in this part due to my relationship to alpine, cold conditions.

This thesis is written as a part of the final semester of the education Bachelor of Architectural Technology and Construction Management. The questions that I try to answer here are for example: Is it feasible to build a Passive House in a colder climate seen from a technical point of view and is it economically reasonable to do so? What has to be taken into consideration when building somewhere where this kind of building standard is not known by local craftsmen and designers? When looking at the Passive House Standards, which were made for central Europe, it is crucial to look at what can and maybe has to be done to the design, the structure and surroundings when building a Passive House in cold conditions. All these questions are probably not answered all positively, but my own knowledge and hopefully yours, the readers will be greater in relation to the field of application of Passive Houses.

Ever since I heard about Passive Houses I was amazed by the fact that it is possible to design and construct buildings which require no additional heating. When thinking back to my days in the Austrian alps, where my parents spent thousands of Euros every year for heating purposes, it is quite obvious that a Passive House would not only have a great impact financially due to energy savings but also ecologically, due to the fact that CO^2 emission is reduced to a minimum. It is therefore obvious to

[1] Ulrik Andersen, Forsker: Kun lovkrav kan forhindre overophededede laveenrgihuse, 04.03.2011

me that people in the building industry have to think about the green building strategy in all projects in order to be successful and make a difference. Ecological and energy efficient building styles are the future and I really hope that I can use my gained knowledge after writing this report in my future career.

This report can be useful to fully understand the entire concept of Passive Houses and if climatic boarders bring up complex issues which have to be solved in order to accomplish the Passive House Standard the way the Passive House Instituted requires. The data and information mentioned in this report can help to make decisions in early stages about the placement and construction of the building and which issues have to be thought about. Therefore this report can be an informative tool for professionals and students. Cold and harsh climates are not limited to little populated areas north of the polar circle, no, they can be found widely across the world, for example in areas with high altitude or glacial areas.

The main source of data in this dissertation has been taken from the World Wide Web. This was done due to the amount of specified up to date information and case studies in this certain field, Passive Houses in cold or arctic climates, while books about Passive Houses cover the concept and methods in a more general way used in moderate climate, as in Germany. These collected data combined with my personal ideas and opinions conclude this bachelor thesis.

Following this introduction the history of Passive Houses will be addressed upon. Chapter two covers the Passive House and its standard and chapter three deals with Passive Houses in different climates. Passive Houses in cold climates are covered in chapter four followed by the conclusion of the thesis.

1. The History of Passive Houses

The actual Passive House Standard was put on paper in 1988 by two professors, Bo Adamson and Wolfgang Feist. A number of research projects and financial help from the German government helped to develop their concept. In 1990 the first Passive House was constructed in Darmstadt, Germany. (Fig. 1[2]) Later in 1996, an institution was founded, the Passive House Institute, also located in Darmstadt, to promote and control the standards of Passive Houses in the world. Since then, due to the rise of cost and lack of fossil fuel, there is an increased tendency to develop more energy efficient housing. Nowadays the numbers of Passive Houses have increased rapidly in central Europe, especially in Germany and Austria, but also in countries with more extreme climates. In 2010 the estimated count of Passive Houses in Germany is over 15,000 and in Austria over 6,000 constructions, while worldwide approximately 25,000 buildings have been constructed.[3]

Figure 1: The first listed Passive House, Darmstadt, Germany

Earlier constructions in style of a Passive House

In the 17th and 18th century Icelanders where forced to build some kind of Passive Houses, since at that time firewood for heating houses was not everywhere available. So a new building tradition began to evolve, turf houses (Fig. 2[4]). These buildings consisted of thick, massive turf walls and roofs which had a great insulating factor. Icelanders found out fast that a well insulated building can stay warm by itself. However window areas and ventilation in these buildings would not be sufficient for today's standards.[5]

Figure 2: Turf houses in Iceland

[2] http://www.passivhaustagung.de/Passivhaus_D/Geschichte_Passivhaus.html
[3] Passivhaustagung, Anmerkung zur Geschichte
[4] http://www.passivhaustagung.de/Passivhaus_D/Geschichte_Passivhaus.html
[5] Passivhaustagung, Anmerkung zur Geschichte

The first real working Passive House was not a house; it was a ship, the Fram from Fritjol Nansen in 1883. (Fig. 3[6]) It was build to travel to the arctic waters for research purposes. This ship was well insulated; it had triple glassing and mechanical ventilation. Fritjol Nansen wrote once in his diary, that it did not matter if there were temperatures of -5°C or -30°C, the interior temperature was always at a comfortable level. He was playing with a thought to remove the radiator, because it was almost never in us.[7]

Figure 3: The Fram, a Polar ship from Fritjol Nansen, 1883

Later in 1973 a Passive House was build in Denmark, Copenhagen, called the "DTH-Zero energy house" (Fig.4[8]). This building is still in use and all passive systems are still working and in original conditions. On the other hand, the active solar cells were not repaired or replaced after a defect years ago. Later on DTH changed their goal of a zero energy standard in favor of a low energy standard[9].

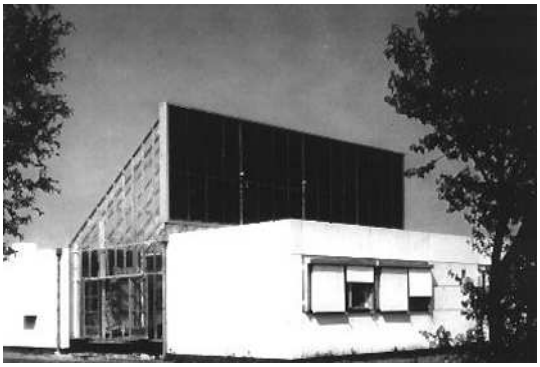

Figure 4: DTH- Zero Energy House, 1973, Copenhagen, Denmark

At the same time low energy buildings have been developed in Germany which was supported by the government, for example the "Philips – Experimenter house"[10].

During the 1970´s and 80´s a lot of research on low energy houses around the world was conducted, which served as a source of inspiration and knowledge for the two professors Bo Adamson and Wolfgang Feist for their idea of the Passive House Standard.[11]

[6] http://www.passivhaustagung.de/Passivhaus_D/Geschichte_Passivhaus.html
[7] Passivhaustagung, Anmerkung zur Geschichte
[8] http://www.passivhaustagung.de/Passivhaus_D/Geschichte_Passivhaus.html
[9] Passivhaustagung, Anmerkung zur Geschichte
[10] Passivhaustagung, Anmerkung zur Geschichte
[11] Passivhaustagung, Anmerkung zur Geschichte

2. The Passive House and its Standard

The basic idea of a Passive House is to reduce the energy usage by 90% over conventional existing buildings.

> "*A Passive House aims at a very low non-renewable energy demand compared to contemporary national standards. This target refers to yearly space heating and cooling energy demand of a Passive House of 15 kWh/m2 per year net floor area, and total primary energy demand for heating, ventilation, electricity for fans and pumps, household appliances, and lighting not exceeding 120 kWh/m2 per year respectively, regardless of energy source. The Passive House Concept is a relatively low-cost method to achieve these energy savings.*"[12]

For example the amount of heating power required to heat a 20 m^2 room are 10 tea lights or the body heat of four people, and this even in the middle of winter[13].

The idea of a Passive House is to build a house which is able to maintain heat, through its special features instead of maintaining heat by an energy input as shown in figure 5[14].

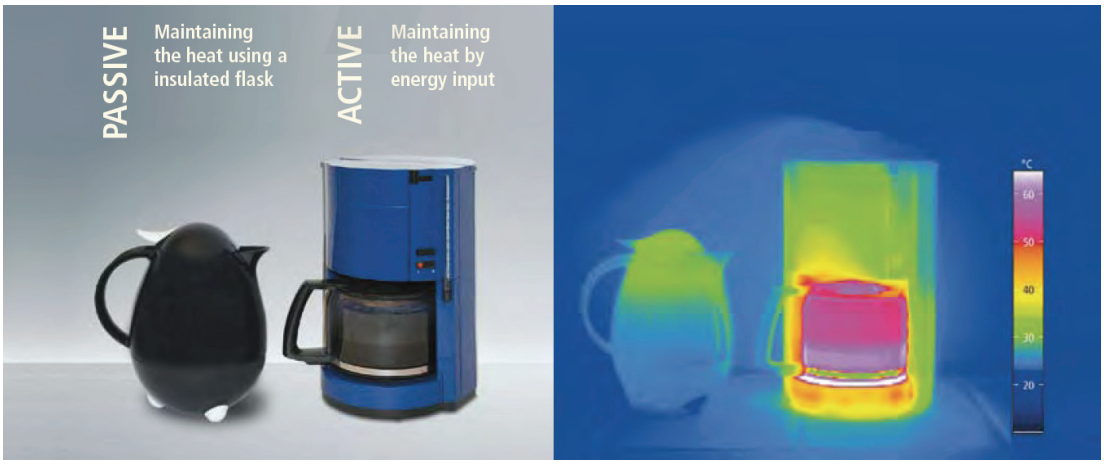

Figure 5: The Passive House Concept illustrated (Passive House Brochure)

It is important to include the below mentioned key elements in the design to accomplish the Passive House building standard:

- Exceptionally high level of thermal insulation
- Airtight building envelope (n_{50}=≤ 0.6 h^{-1})
- Thermal bridge free construction
- Low energy glazing and well insulated window frames which reduce line losses

[12] Promotion of European Passive House, Passive House, Definition
[13] Passive house brochure (Built for the future)
[14] Passive house brochure, p. 10

- Mechanical ventilation with highly efficient heat recovery
- Orientation of the building

2.1. Definition of the Passive House Standard

The Passive House Standard is a construction standard, developed by the Passivhaus Institute in Germany,[15] especially with the area "between northern hemisphere latitudes 40 degrees (Madrid and Ankara) and 60 degrees (Oslo and Helsinki)"[16] in mind. The Standard can be met using a variety of design strategies, construction methods and technologies and is applicable to any building type[17].

> "*The Passive House Standard is a specific construction standard for buildings with good comfort conditions during winter and summer, without traditional space heating systems and without active cooling. Typically this includes optimized insulation levels with minimal thermal bridges, very low air-leakage through the building, utilization of passive solar energy and internal gains and good indoor air quality maintained by a mechanical ventilation system with highly efficient heat recovery.*"[18]

Every building style has advantages and disadvantages. There are many reasons which speak for a Passive House. Some of the main advantages can be found on almost every homepage or book related to Passive Houses. The most lucrative advantages are as following:

- Up to 90 % energy savings in comparison with a conversional building and therefore a small CO2 footprint. (Fig. 6[19])
- To a large extent independent of rise of energy prices
- Longer life time of the building parts through air and moisture proof constructionReduced danger of fungus, but only when insulated right
- No cold walls and draft
- A lot of daylight
- Almost perfect indoor climate through constant air exchange and sound reduction all year around

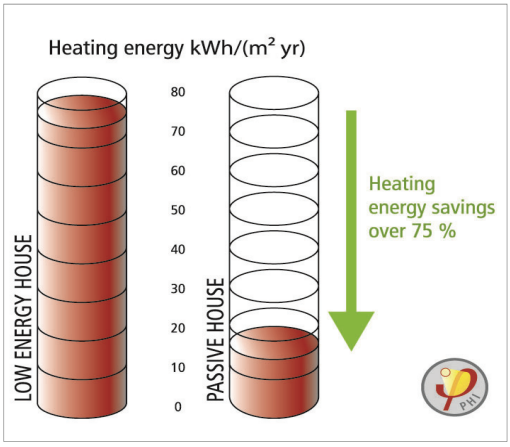

Figure 6: Heating-Energy saving diagram

[15] www.passiv.de
[16] Dr. Wolfgang Feist,Passivhaus Institut, Passive House Brochure (Built for the Future), 2010
[17] Sustainable Energy Ireland (SEI), Passive homes, Guidelines for the design and construction of PH, 1.1 Passive house and the Passivhaus Standard, 2007
[18] Sustainable Energy Ireland (SEI), Passive homes, Guidelines for the design and construction of PH, 1.2 Definition of the Passivhaus Standard, 2007
[19] http://passipedia.passiv.de/passipedia_en/basics/what_is_a_passive_house

But of course as every item which can be compared to another, not all is positive, and when the item is a building, these disadvantages can be quite serious and costly. The main disadvantages are as following:

- Most likely higher construction cost, especially for one family houses
- Cost of ventilation system
- Most likely low air humidity in winters
- Possibility of problems with installation of ventilation units due to lack of knowledge.

Most of the mentioned disadvantages can be eliminated when designed, constructed and installed the right way. Another important part is that the residents of a Passive House have to be aware of in what kind of building they are living in. When moving from a standard building into a high sufficient Passive House some issues and questions come into most people's mind. For example the following:

- **It is a common wisdom that a construction has to "breathe", but can a Passive House "breathe" enough when it is build such airtight?**
  No, it cannot! But this is solved by the ventilation system which is a necessary piece of a fully working Passive House. The airtight envelop prevents moisture penetrating the construction and the ventilation system will remove humidity safely[20].
- **Are you allowed to open the windows in a Passive House?**
  Yes, of course. The request of opening windows in standard buildings will arise when air change is needed or when the internal temperature surpass a comfortable indoor climate. These issues are almost eliminated in a Passive House; the ventilation system provides fresh air and a comfortable temperature throughout the year[21].
- **Isn´t it to cold during the winter?**
  In some cases this problem came to reality, but again, when designed right and constructed the way it should be done, this issue can almost be eliminated.

The environmental benefits of a Passive House construction are crucial for the future of the planet in times of global warming and future scarcity of natural recourses. The points below summarize those benefits:

- **Sustainability**: According to the EU Commission it costs 50 - 400 % more to produce an extra kilowatt of electricity than to save it.

[20] STRUCTURES-Buildings with integrity, Frequently asked questions on Passivhaus
[21] STRUCTURES-Buildings with integrity, Frequently asked questions on Passivhaus

- **Reduced CO2 emissions**: An average household is responsible for 6,000 kg of CO2 emission a year. Living in a Passive House the same household emits only 2,100 kg of CO2 a year.
- **Noise protection**: Thick and well insulated structures also provide effective sound insulation. Quiet rooms in a noisy environment (traffic, industry, etc)[22]

2.2. The economy of Passive Houses in moderate climate

The economic part of a Passive House has to be split in two sections, the construction cost and the running cost. It is only reasonable to build a Passive House when the combined costs are lower than the combined cost of a conventional building. When constructing a Passive House some extra cost has to be expected, for example in the design phase and materials used.

The construction cost

A Passive House project needs to be designed carefully. The time spent to do so is probably more than for a normal house. It starts when finding the right placement and orientation of the building which is a key factor of a Passive House, because of the usage of the passive solar energy for daylight and for heating the building. Within the same issue it is important to have the right amount of window area and its location. Due to the special requirements of the Passive House building parts it can be quite challenging to design them the way it will be reasonable to construct and assemble.

The materials used to establish the Passive House Standard also have an impact on the cost. The amount of insulation used will raise the cost of such a building, but due to new building regulation, for example the Danish Building Regulations[23], the difference will not have the same impact as it used to. The additional cost of highly insulated window frames with triple glazing can be anything from 5% higher than conventional double glazed sealed units.[24] The highly energy efficient ventilation system with a high level of heat recovery will also add more to the cost as well as a more complex execution to achieve the air tight envelope, the air tightness test and some various systems for saving energy like a heat pump or sun collectors.

When constructing a Passive House some cost savings can also be made. There is no conventional heating system required (radiators, floor heat) nor the associated fuel storage and chimney.

[22]Passivhaus Design Atelier, why passive house, Environmental Benefits, 2010-2011
[23] Dansk Bygnignsreglement 2010, (BR 2010)
[24] Double Versus Triple Glazing, Matthhew Challis, December 11, 2010, http://www.ehow.com/facts_7484671_double-versus-triple-glazing.html

A simple curve is shown in figure 7[25] with the additional cost and savings within a Passive House construction.

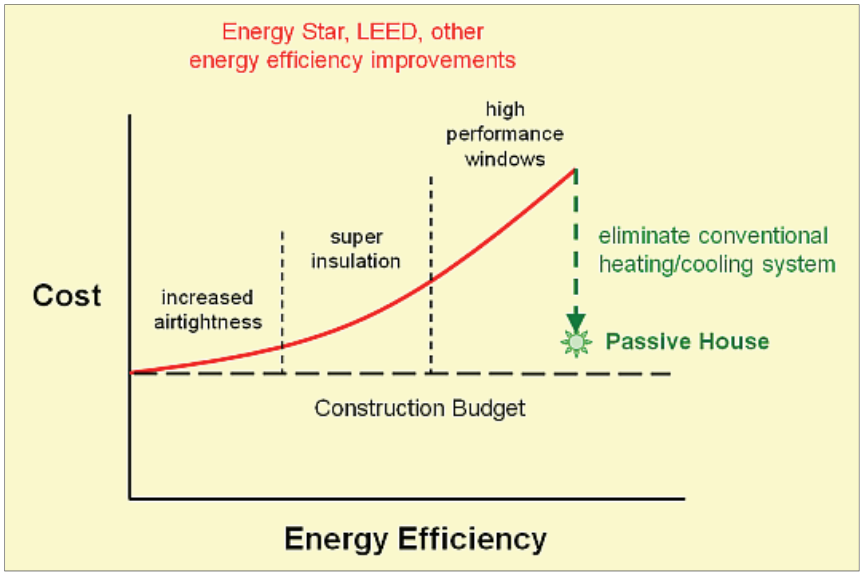

Figure 7: Simple schema of additional cost and savings

The increased construction cost of a Passive House can vary between 0% and 15 %. But due to new and more demanding building regulations and the demand of low energy buildings it will rather be lower than higher. Nevertheless it always depends on the project itself.

The cost seems to increase proportionally with the size of the project, i.e. the highest costs are for single family houses and the lowest costs are for larger apartment buildings. In comparison to a low energy building standard the cost difference is only 3 – 5%, with a saving of 50 – 80% in energy and running cost[26].

The running cost

The running cost of a Passive House (Fig. 8)[27] is significantly lower than in a conventional building, up to 90 % energy savings in comparison with a conversional building and it will pay off in less than twenty years. However in particularly favorable situations, pay-back can be as little as 4 years. It always depends on a specific project. Twenty years might seem a long time but represent only a fraction of the lifetime of a house or an apartment. Houses might be designed to last 50-100 years but often function as homes for much longer.[28] The lifetime of a Passive House probably exceeds the lifetime of a regular building due to the high quality of construction, the Passive House features and

[25] HarvestBuild Associates, Mark Hoberecht
[26] Passive Houses in Cold Climates, Passive House Projects in Norway – an Overview, Chap. 1, 2007
[27] Isover,Comparing heating costs of existing building
[28]Passive On, CD 5, Long description,The passive way to saving

materials used. This keeps moisture out of the construction, minimizes the appearance to mold and rot and is the reason for the low maintenance cost.

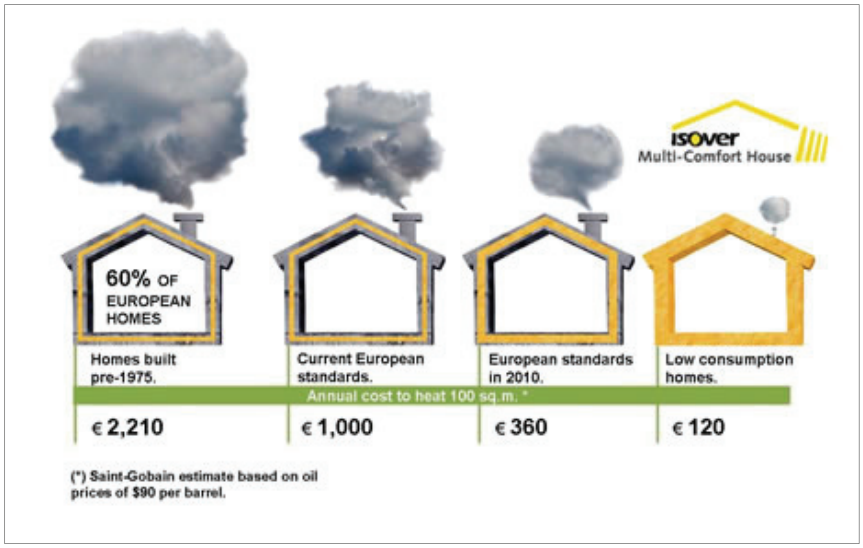

Figure 8: Comparing heating costs of existing buildings

3. Passive Houses in Different Climates

As mentioned before, the Passive House Standard was developed for central Europe and it´s climate. But the regions Passive Houses are constructed in have expanded worldwide, also to more extreme climates, such as in arctic areas where the temperatures can drop to well below 30 degrees Celsius or as in southern Europe where the peak temperature can be well above 30 degrees. The concern in these climates is if the Passive House Standard can be used in these conditions? And if so, what has to be done to achieve that successfully?

It has to be taken into consideration that each country has a specific building tradition and the materials available are adapted to the climate of the specific country. On the other hand the goal is to reach the same Passive House Standard in all climates and in all countries. There is a lot of experience about how to design and build a Passive House in a central European climate, but it would be a pitfall just to apply the central European Passive House design without taking the traditions and conditions of different countries into consideration.

> "*The physics are the same all around the world. So the problem to build almost self-sufficient houses (i.e. Passive Houses) is well defined. The physical equations are the same only the boundary conditions vary. Thus the solution method can well be applied independently of the circumstances in order to find the appropriate way of Passive House design in a specific country and climate.*"[29]

It is fortunate that despite of different design the leading principal remains the same regardless of the climate. In case of heating and cooling, insulation, heat recovery, highly insulating windows, passive solar design and other measures are important to reduce the energy demand to the maximum of the Passive House Standard. In some climates it will be easy to achieve while in other climates it will be more difficult. The same applies for the cooling. The choice of window sizes and quality, shading and orientation of the building and the reduction of internal heat loads are a very efficient way to keep the interior of a Passive House at a level where the ventilation system can do the rest to keep a good indoor air quality with a small amount of cooling energy. It is important that the main characteristics of a Passive House are not negatively influenced.

There are some rules of thumb which are valid for all climates:

- *"You should keep comfort at a high level. Passive Houses should be well known as the most comfortable houses – in any country and within any climate. Be aware that all persons would like to live in a comfortable indoor climate and that all of them should have a right to do so. Therefore, in the long run, no solution will persist which will not contribute to a better indoor climate.*

[29] Tamas Banki, Passive Houses in different climates, 2011

- *The solution should be simpler than ordinary buildings/systems used so far. Only affordable solutions will be attractive in a competition with conventional technology like standard air conditioning.*
- *It is not necessary that the solution will not need any conventional energy demand ('zero energy solution') - that might be very expensive. It is sufficient to use a lot less energy than in ordinary systems. At a factor of 4 to 10, the energy conservation is likely to be high enough to pay for the extra efforts needed.*
- *Insulation might be a good idea in all climates.*
- *Shading will be absolutely necessary in all climates with high solar radiation during summer.*
- *Heat recovery will be necessary in all cold and in all hot climates. If the houses have a ventilation system, which will be a good idea if external temperature will be lower than 8 °C or higher than 32 C in a relevant time period, the supply air ducts may well be used to transport heat during the heating season, cool air during the hot periods and dry air to dehumidify if necessary.*
- *Using very low amounts of auxiliary energy is an important precondition for passive solutions. The fans in ventilation systems, for example, must use highly efficient electronically commutated motors. This is obvious in the case of recovery of cooling energy, but it is necessary in systems for heat recovery, too. On the other hand - don't hesitate to use a ventilator; moving air requires much less energy than heating or cooling it significantly.*
- *In many cases the ground can be used as a heat or cold buffer. Vernacular architecture in a country may indicate whether ground coupled systems are an opportunity. The traditional solution may be very expensive, however - like huge air channels or earth buried houses; that will not be a solution reproducible for the future. But there are less expensive solutions using modern technology like earth buried ducts or ground probes."*[30]

Due to the amount of manufacturers located in Europe which produce Passive House components it is almost no problem to find the suitable parts for every design and construction in these areas. The situation is different in countries where passive housing or low energy housing is not as common. The lack of knowledgeable designers, craftsmen and even the future users of such a building is an issue.

[30] Passipedia, Passive Houses in different climates, Practical hints

The energy demands for Passive Houses have been adapted to southern European countries and the Nordic countries above 60° latitude. So there are different definitions of energy demands for Passive Houses in different climates as seen below:

- **Central Europe:**
  - Heating and cooling energy demand 15 kWh/m^2
  - Primary energy demand 120 kWh/m^2
- **South Europe:**
  - Heating energy demand 15 kWh/m^2
  - Cooling energy demand 15 kWh/m^2
  - Primary energy demand 120 kWh/m^2
- **Nordic countries above 60° latitude:**
  - Heating and cooling energy demand 20-30 kWh/m^2 according to location
  - Primary energy demand 120-140 kWh/m^2
- **All climates:** Air tightness n_{50} < 0c6 1/h

3.1. The economy of Passive Houses in different climates

The cost of a Passive House in more colder or warmer climates does slightly differ compared to building in a moderate climate due to the different temperatures, surroundings, the amount and strength of sunlight, the wind and possibility of shelter.

The construction cost itself should not differ much beside of the amount of different materials needed to achieve the Passive House Standard. The main issue to solve in Mediterranean climate is to prevent the building from overheating and that can be controlled through, for example a different building design, shutters and efficient cooling system. The main issue in cold or arctic climate is to keep the building warm and comfortable, also during cold winters. That can be done by adding more insulation material, using different design, the position of the building and installing windows with an even lower U-value.

The goal of every low energy construction is to lower the running costs the way that the higher construction cost is being compensated in prior of the lifetime of the building itself. The cost of cooling a common building in warmer areas always has a great impact on the running cost but due to well insulated building parts and high efficient cooling and ventilation system in Passive Houses these certain costs will be lowered significantly.

The same goes for the heating cost of a Passive House in a cold climate, it is supposed to be much lower than the heating cost of a conventional house in these areas. But it is not only the running cost which speaks for a Passive House, it is also the high level of comfortable indoor climate provided

all year long in such a building and last but not least the global impact with the reduction of CO_2 emission mentioned earlier. To gain more passive heating energy a dinner invitation or even a pet can do the trick (Fig.9)

Figur 9: Heating of a Passive House

4. Passive Houses in Cold Climates

Passive Houses in cold climates are not as common as in central Europe, although the savings in view of running costs of such a building would be far more than in moderate climates. But the lack of knowledge and Passive House materials does not help to change this fact. Another reason for this is the construction cost of such a building. Due to comparatively cold weather conditions more sufficient materials and technical equipment have to be used to achieve the Passive House Standard.

The main problem is the extreme weather conditions such as annual mean temperatures below 0 °C or peak temperatures of under -30 °C. To reach a similar insulation value in these areas as in central Europe, the amount of insulation will probably be more than two or three times as much. These extreme temperatures will have an impact on the ventilation system as well. Another problem could be greater ground frost conditions. This could challenge or have an impact on the design. For example a research station in the Antarctic, which is a Zero Energy Building (fig. 10[31]), is elevated from the ground to avoid cold transmission, while other buildings in cold areas are equipped with a basement which penetrates the frost in the ground.

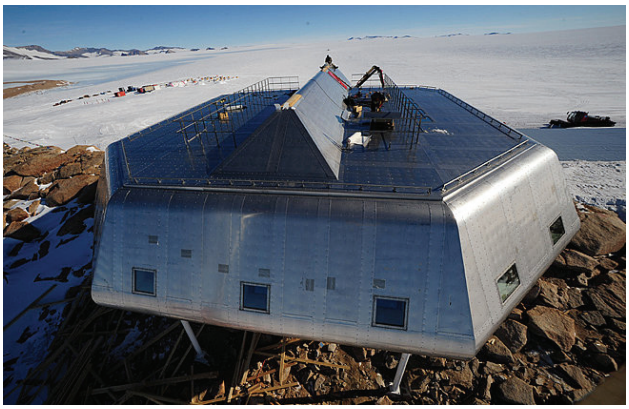

Figure 10 Research Station in Antarctica

One very important issue is the amount of daylight in areas high up in the north or above 60° latitude. During the winter months sunlight is quite rare, so the gain of passive or even active solar energy will be at a very low level. During the summer months a completely different scenario occurs, where the sun does not leave the horizon for a long time. These extreme circumstances are not perfect for a building standard which uses passive solar energy for keeping the heating demand on such a low level, as the Passive House does.

The next subchapter covers two different cases of Passive Houses in harsh climates which should give a better understanding of the challenges and solutions in those situations.

[31] http://knowledge.allianz.com/energy/?701/princess-elisabeth-antarctic-station

4.1. Examples of Passive Houses in cold climates

The Schiestlhaus, Austria

Location:

In the years 2004-2005 a house called the "Schiestlhaus" was constructed in Austria at 2154 m above sea level. (fig. 11 and 12[32]) This was the first Passive House "Schutzhuette" (emergency dwelling) over 2000 m above sea level in the Alps. Although this building is located in central Europe it may nevertheless be compared to conditions in cold climates. In this altitude and location during the winter months temperatures can drop below -30 °C and storms can reach wind speed of more than 160 km/h. When taking the wind chill into consideration temperatures of -60 °C can be reached.[33]

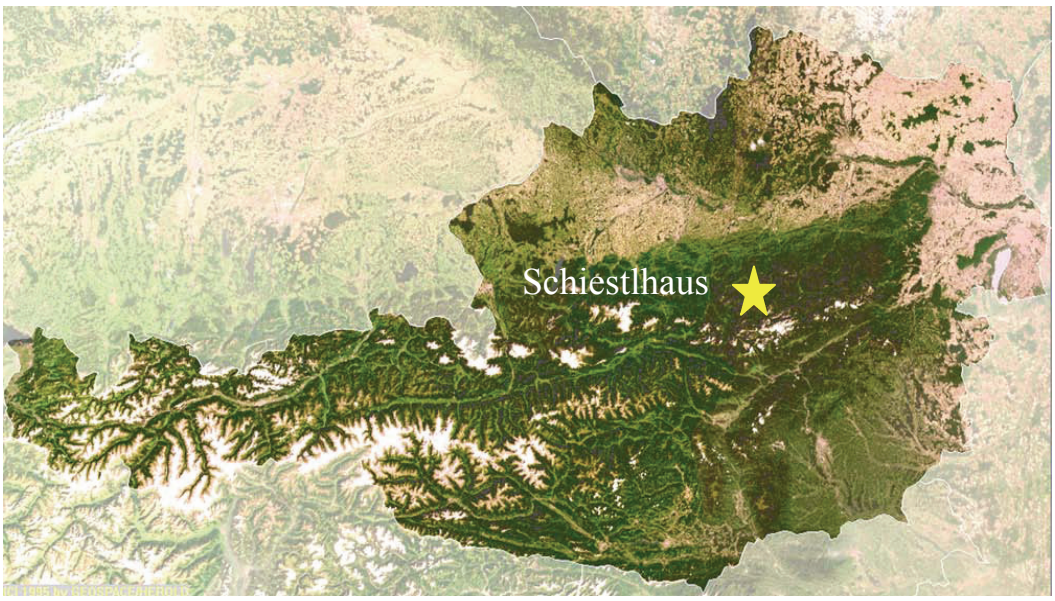

Figure 11: Map of Austria with location of the Schiestlhaus

Facts about the building:

To achieve the Passive House Standard it was necessary to adopt the design and techniques to the location of the building. The Schiestlhaus was oriented to the south for the optimal use of daylight and passive solar heating power. To cover the electric and warm water consumption approximately 50 m2 of solar heat collectors and 68 m2 of solar cells were applied to the south façade and the roof. Even the layout of the room divisions have been planned under the criteria of low energy consumptions. Due to the location of the building a backup energy system was installed which is powered with Raps oil. The ventilation system used is also highly energy efficient with a heat recovery of 85 %. For really extreme conditions an emergency heating source was installed, a wood burning stove with an

[32] Di. Robert Salzer, Konstruktiver Holzbau, Schiestlhaus am Hochschwab 2154 m
[33] Berichte aus Energie und Umweltforschung, Schiestlhaus am Hochschwab 2154 m

output of 10 kW of heat. This feature is an addition to the Passive House Standard and will only be used when needed. 100% of the water supply is covered by rainwater which is cleaned and stored in ten tanks, approximately 34 m^3.

The entire construction is highly insulated and air tightened, the external walls reach a U-value of 0,12 W/m^2K, 0.11 W/m^2K is the value for the roof and the basement floor slap achieves a value of 0,18 W/m^2K.

Figure 12: Schiestlhaus during the harsh winter months

The result of the combination of all this technique and design is giving an annual heating demand of 14 kWh/m2. The passive solar energy brings an input of 80% of the entire heating demand and 70% of the entire electricity usage is covered actively by the sun.[34]

Economy

Because of the extreme location the construction cost is hard to compare with a common, same sized Passive House. In means of transport, helicopters were the main tool in the construction process. Materials and building parts were flown to their destination sometimes from storage areas loaded 45 flying minutes away. Therefore the 2.000.000 Euro construction cost is only relative.[35] (fig. 13) In theory, there is almost no running cost, beside of the firewood and the Raps oil for extra heating and electric purposes.

Figure 13: Material transport with helicopter, Nachhaltig Wirtschaften

Summary

Location:	Exposed on a mountain ridge
Orientation:	South
Design:	Efficient for harsh climates
Technique:	Top of the range

[34] POSArchitekten, Schiestlhaus Baudaten; Arch. Fritz Oettl; nov. 2004; (www.pos-architekten.at)
[35] Berichte aus Energie und Umweltforschung, Schiestlhaus am Hochschwab 2154 m

Single family house at Tromsøya, and 7 dwellings at Storelva, Tromsø, latitude 69.6°N

Location:

These buildings are located high up north in Norway and therefore in a more extreme environment (fig. 14). The single family dwelling at Tromsøya was completed in December 2005, and was the first Passive House project to be completed in Norway. The seven dwellings at Storelva were completed in April 2007. Tromsø has a relatively cold coastal climate, with a yearly mean ambient temperature of 3.0°C and a design winter temperature of -17.5°. During some summer month's the sun does not set from the middle of Mai until end of July, but the opposite will be experienced during the winter months. From the end of November until the end of January the sun will not be seen on the horizon. [36]

Figure 14: Map of Scandinavia, Tromsøya

Facts

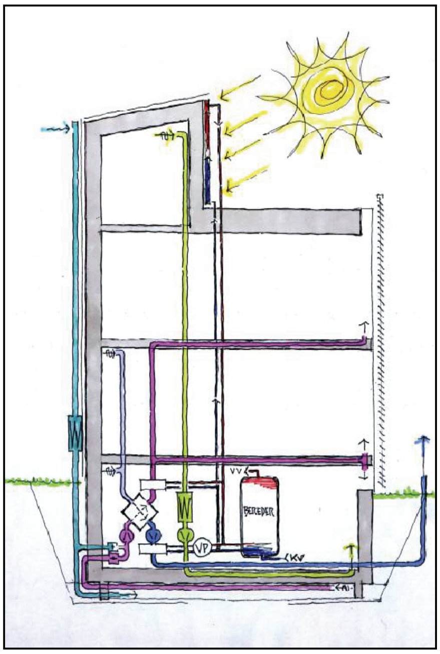

Figure 15: Schematic concept

Like most of Passive House constructions the orientation of this building is to the south to gain most of the solar energy as possible, as shown in figure 15. The dwellings are constructed in massive wood elements (from KLH Massivholz, Austria). The exterior walls have 25-30 cm of mineral wool, the roof has 36 cm of insulation and the floor has 15 cm, which can be considered little for the circumstances and location of the houses. The ventilation system is coupled to an earth to air tube collector buried beneath the basement and a compact heat pump unit with heat recovery. The dwellings have no conventional heating systems; the entire space heating load is covered by the ventilation system. A solar collector system produces most of the warm water during the spring and summer seasons. The total end energy use is estimated to be less than 50 kWh/m^2/yr for all dwelling units. The heating energy load for all dwellings is estimated to

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[36] Passive Houses in Cold Climates; Session 4; Passive House Projects in Norway – an Overview, Chap. 1.1.1, 2007

be below 5 kWh/m^2/yr. The developer has estimated the total construction cost of the project to be about 10% above typical construction cost. The indoor temperatures in the dwelling at Tromsøya have been measured during the warmest summer days, and are reported to be in the range of 22-23°C. The windows are equipped with an exterior automatic shading system. On the other hand the energy use for the Tromsøya house has not been measured yet, but all the dwellings are to be monitored. Special challenges reported were lack of knowledge and skills among HVAC, (Heating, Ventilation, Air Condition) and electrical engineers, so the architects had to deal with the technical matters on their own. Also, the special construction method related to the massive wood elements, were new to the Norwegian construction practitioners. However, the thermal bridge challenges related to the massive wood elements were found to be relatively easy to solve.[37] Due to little insulation and the northerly location of the dwelling it would be interesting to see if the energy demand for heating has been as low as estimated (5 kWh/m^2/yr), but unfortunately that information was not available at the time of writing.

Economy

No documented cost was found, but when looking at the facts mentioned above my guess would be that the difference to a common building in this area would be within the 15% mentioned in chapter 2.2.

Summary

Location:	High north, less sunlight in winter, cold winters
Orientation:	South
Design:	Efficient, plain design for cold climates, well insulated
Technique:	Top of the range

[37] Passive Houses in Cold Climates; Session 4; Passive House Projects in Norway – an Overview, Chap. 1.1.1, 2007

4.2. A certain Passive House applied to different locations

In the years between 2002-2006 has been an increased interest of low energy houses in Norway. Over 3000 low energy buildings have been erected, are under construction or in planning. Over 10 % of these constructions have Passive House amities with a space heating demand of less than 15 kWh/(m2a).[38] This chapter shows how the amount of insulation and various Passive House parts have to change to achieve the Passive House Standard.

The different locations are placed in Norway and central Europe like Zurich. (fig. 16)

Figure 16: Map of Scandinavia, Location points

In these locations the difference of the climatic conditions varies from moderate to arctic climate. The four different locations are Zurich, Oslo, Lillehammer and Karasjok. The last mentioned is one of the most northern European populated areas. The annual temperature in these locations vary from 5.7°C in Oslo, 3.3°C in Lillehammer and -2.5°C in Karasjok, which is actually colder than in Nuuk (Greenland), while the temperature in central Europe is approximately 9°C.

To successfully apply the Passive House Standard in these cold areas the amount of insulation has to be adjusted to the temperatures, as can be seen in table 2. Normally the PHPP[39] program is used for designing a Passive House, but the following case used the SCIAQ Pro[40] to simulate space heating

[38] Passive houses in cold Norwegian climate, 2006
[39] Passive House Planning Package, 2007
[40] Passive houses in cold Norwegian climate, SCIAQ Pro, Simulation tool, 2006

load and peak demand. The Main reason to use SCIAQ Pro instead of the PHPP, is due to the fact that PHPP does not currently offer the necessary range of Norwegian climate data.

Data of a Passive House located in Oslo, Norway.

Data	Detached house located in Oslo
Heated floor area	160 m^2
Heated air volume	355 m^3
External wall area	180 m^2
Windows ad door area	35 m^2
Roof area	80,5 m^2
Floor area	80,5 m^2

Tabel 1: Data of the investigated building[41]

Energetic building standard for detached house section, necessary to meet the Passive House requirement of 15 kWh/ (m^2a)

Building part	Oslo W/(m^2K) mm insulation	Lillehammer W/(m^2K) mm insulation	Karasjok W/(m^2K) mm insulation	Zurich W/(m^2K) mm insulation
Roof construction	U=0.07 App. 550	U=0.07 App. 550	U=0.06 App. 800	U=0.14 App. 400
External wall, main facade	U=0.11 App. 450	U=0.11 App. 450	U=0.07 App. 800	U=0.15 App. 350
External wall, gable wall	U=0.10 App. 450	U=0.09 App. 450	U=0.09 App.650	U=0.15 App. 350
Floor slap on ground	U=0.08 App. 450	U=0.08 App. 450	U=0.07 App. 650	U=0.15 App. 300
Windows (total U-value)	U=0.65	U=0.54	U=0.35	U=0.80
Ventilation , heat recovery	87 %	92%	99%	80%
Air tightness	N50 = 0.45 ach	N50 = 0.45 ach	N50 = 0.3 ach	N50 = 0.6 ach

Tabel 2: Data of the different building parts[42]

Table 1 lists data of a Passive House located in Oslo, Norway which was planned and designed for the climate conditions there. Exactly this building was then analyzed and the properties of the building parts and systems used were changed so it could keep the Passive House Standard in more extreme climates, as seen in table 2. But the design of the building and the window area were

[41] 10th IPH Conference 2006, Passive houses in cold Norwegian climate, by Tor Helge Dokke, Inger Addresen
[42] 10th IPH Conference 2006, Passive houses in cold Norwegian climate, by Tor Helge Dokke, Inger Addresen

not changed in this calculation which could have a great impact on the entire heat frame of the building.

Looking at table 2 one can see what impact the cold climate has on the way the Passive House has to be constructed, which technique and materials have to be used and if it is even realistic to construct a Passive House with the same criteria used in central Europe. For example the insulation for the roof construction in Oslo and Lillehammer needs to be approximately 550 mm compared to 400 mm in central Europe and 800 mm in the extreme climate of Karasjok. Another example is the sufficiency of the ventilation system's heat recovery, in Oslo the sufficiency could be around 87%, in Lillehammer around 92%, in central Europe around 80% while in Karasjok it would have to be around 99% which is not yet achievable with today's technology. In the extreme climate of Karasjok, where the annual temperature is -2.5°C and a design winter temperature of amazing -43.4°C it will be very difficult with the current technology to meet the Passive House Standard as mentioned before. But when adjusting the heat demand from 15 kWh/m^{2}a to 20-30 kWh/m^{2}a and using state of the art technology and materials it could be possible.

The data in table 2 is very good for a first impression of how huge the impact of a climate change could have on a building, but when designing a building especially for these harsh climates it could probably be easier to achieve than it looks.

Economy

Due to lack of information it is hard to specify the cost of projects in arctic climates and cost difference to Passive Houses in central Europe. But it is clear that the construction cost will be significantly higher. Nevertheless the construction cost of a common building in these areas will probably exceed the construction cost of a similar building in moderate climates. The running cost on the other hand would be radically reduced in comparison to a common building if the Passive House Standard could be achieved in these areas.

4.3. Issues to think of when designing a Passive House in cold climates:

When designing a Passive House for a cold climate there are several issues which have to be taken seriously into consideration for example, the current technology, the location, the orientation of the building and the design, amongst other things. These issues will be covered here below.

Technology available today:

- Top of the range triple glassed windows can reach an U_w-value of 0.65 W/m^2K.
- Ventilation system with up to 95 % heat recovery
- Highly efficient heat pumps
- Photo voltaic cells and solar collectors (which are not so efficient in northern countries with only little daylight during the winter months)

Applying the best of the best is a great way to lower the energy consumption. But it is also a quite costly way of doing so.

Influence of the location

A really important point and also one of the first is to find a good location for the building. When the structure is placed on an elevated location the gain of a passive and active sun energy is the highest possible in the certain area, but there is also a downside to this. The building will be exposed to all kind of weather conditions and the cold, arctic wind will cool it down for sure to a degree that the passive heating and the ventilation unit with the heat recovering system would not cope with in order to reach the demand of a Passive House.

The opposite would be to place the building in a depressed area. In such a location it will be sheltered from weather conditions. But beside of less solar energy another disadvantage occurs, namely cold air will always stay in such locations while warmer air rises. This is the reason why the coldest areas are most often in depressions, not taking extreme altitudes into consideration. Therefore a location like this in a cold climate is not really suitable for a building which should not require any active heating.

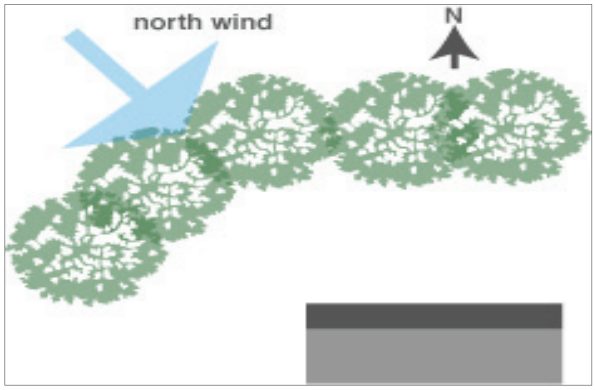

Figure 17: Wind shelter for a building

To summarize the above mentioned the location of a Passive House in extreme climates should be sheltered from weather conditions which still gives the maximum solar energy. The easiest way to provide a wind/weather shield for a building would be looking for a place near a forest or plant

trees on the most wind exposed side (Fig.17[43]). Another solution could be to locate the building in a denser area where every construction shelters each other.

Influence of the orientation

The next step is to find the right orientation of the building. In the northern hemisphere it will be the south façade which will have the greatest impact of the solar energy. A deviation of maximum ±30° (Fig. 18) from the south orientation will not change a lot in relationship to the annual heating and cooling demand of the Passive House, then, however, both overheating and increased heating demand will appear more often. In the range between 60° and 90° direction from the south, overheating can occur quite frequently.

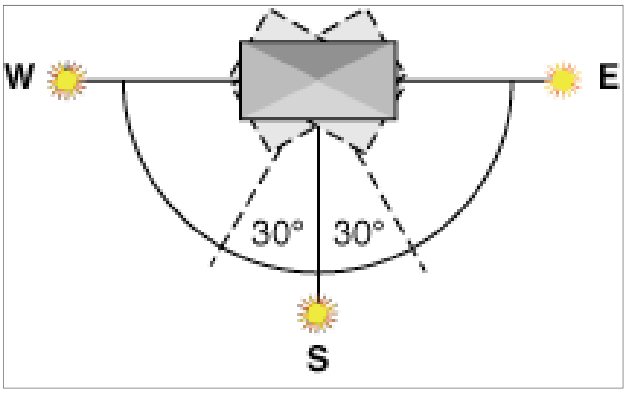

Figure 18: Schematic orientation

With a 90 orientation (West or East), the annual heating demand will already be reached at 16 kWh/(m^2a). When orientating further away from the south the changes will be very small. In case of winter, a northern orientation is hardly worse than an east or west orientation. This is different in the summertime, when rotating the orientation more to the north the cases of overheating almost disappear. Between ±45° toward north the minimum hours of overheating hours are reached, around 10 %. This is based on central European climate, where overheating of a Passive House is an important issue, while the main issue for Nordic/arctic countries is to keep the buildings warm with as little energy effort as possible. Based on the above mentioned it becomes understandable, why buildings with large window areas, especially which are orientated to the east-west are problematic in case of an even and comfortable indoor climate. [44]

Design of the building

In the beginning Passive Houses were build in a rather boring but energy efficient architectural aspect, four walls, a roof which was planned to host solar panels and large window areas facing the south (fig.19). This was done to minimize façade areas and possible cold bridges as much as possible. But during the last 20 years, which is the existence of the Passive House Standard, materials and technical equipment has improved, so it is possible to build a Passive House in great architectural variety. This is also one of the main reasons why this concept is becoming so popular.

[43] Greenspec, Design, External enviroment
[44] DR. Wolfgang Feist, Das Passivhaus im Sommer, 6. Der Einfluss der Orientierung, 2007

When building a Passive House in a cold climate the design of the building becomes more important than in central Europe. Not every design is suitable in such climates. It is almost possible to say that a minimalistic design will also be the most lucrative in case of energy efficiency. Less surface area will result in less heat loss which will help to keep the energy consumption for heating purposes lower. For example a fancy design with a lot of external wall areas, extremely large window areas and counter lever floor slaps will have a great impact on the heating demand. The design shown in figure 20[45] would be quite challenging in cold or arctic climate where sun light is rare in the winter months and the temperature can drop far below zero. Even the best energy efficient windows available today are not as efficient as a well insulated wall. In this case the gain in daylight and passive solar energy has to be compared to the heat loss of these areas. The ratio of window and wall area has a great impact on the energy consumption, especially in extreme climates.

Figure 19: First Passive House, Darmstadt, Germany

Figure 19: Passive Solar House

All these points mentioned in chapter 4.3 can help to lower the energy demand of the building and when fulfilling these points in moderate climates the problem of overheating or cold rooms will be almost eliminated all year long.

In arctic climates overheating will only be a small issue while keeping the building warm will have a greater impact in the energy consumption. Therefore the Passive House design has to start right in the beginning when searching for a suitable location and orientation for the climate it is built in.

When constructing a Passive House in a cold climate it is very important to think about the materials used are more suitable than others. Some examples are listed below:

Which structure is suitable

The structure of a Passive House can be achieved in different ways. This can vary from the project size, the building tradition of the country it is constructed in and of course the design of the project. While single family houses are quite commonly constructed with a timber frame, larger office – or apartment complexes are usually constructed with concrete elements or steel frame. But to achieve the

[45] http://www.sustainablehousingdesign.com/how-to-become-self-sufficient-with-a-passive-solar-house/

Passive House Standard almost every construction method can be used, like massive timber elements, steel frame, even turf walls can be suitable. But when thinking about a project in Norway or Finland the timber frame construction will be the most common way to construct a single family house, as is traditional in northern European countries

To find out which material is best suitable for cold climates a look at the thermal properties can be quite helpful. The main structural materials are to be seen in table 3.

Examples of structural materials:

Material	Thermal conductivity (W/mK)	To reach U-value of 0,13 W/(m^{2}K) Amount in meters
Conventional concrete	2,100	15.80
Construction wood	0,130	0,98
Brick	0,800	6.02
Steel	36.00	

Tabel 3: Different materials and their thermal properties[46]

When looking at the thermal conductivity of the possible structural parts, like concrete, structural wood and steel the numbers speak for themselves. When comparing structural wood, which has a low thermal conductivity of 0,13 W/mK, with concrete, 2.100 W/mK, and steel, 36,00 W/mK, it is clearly shown which building material is more suitable for a Passive House. In a moderate climate it is not such a problem, because it can be compensated by for example adding a bit of insulation more in the structure. In cold climate, where the amount of insulation is already far more it is better to use the most suitable building material possible for the climate.

Another aspect is the mass of the materials. When concrete gets heated to room temperature it will keep that temperature longer than steel or wood, and during nights, where no passive solar heating occurs, concrete will slowly cool down while heating the surrounding air volume. This makes it also quite a good solution for a Passive House. The downside is that the thickness of the building part will be more than in a timber construction to reach the same U-value.

When also taking sustainability, which is on everybody's mind these days, into consideration, wood as a building material in the Nordic countries is more suitable than concrete. The sources are nationally reachable and it is a self growing material.

Suitable insulation

In table 4 some insulation types are listed with their thermal conductivity and the thickness needed to reach a U-value of 0,13 W/(m^{2}K). The last two types of insulations mentioned – Vacuum insulation -

[46] Passivhaus Haustagung- Waermedaemmung von Passivhaeusern, 2002

would technically be perfect considering the thickness needed. Imagine when building two different types of building parts with the same thermal properties, one with a typical insulation (0,300 m) and the other with a vacuum insulation (0,015 m). The difference in thickness would be enormous. This would change the net area of the building by a large amount, especially in a cold climate where the amount of insulation needed to reach a reasonable U-value increase compared to central Europe.

Some insulation materials:

Material	Thermal conductivity (W/mK)	To reach U-value of 0,13 W/(m^{2}K) Amount in meters
Typical insulation	0,040	0,300
Insulation	0,025	0,188
Super insulation	0,015	0,113
Vacuum insulation (silicic acid)	0,008	0,060
Vacuum insulation (high vacuum)	0,002	0,015

Tabel 4: High tech insulation materials and their thermal properties[47]

But all good sides also have a downside. Beside the higher cost of these high tech materials, specially trained craftsmen would be needed, but nowadays it is still not possible to neither cut nor adapt these materials at the building site. These high tech materials still have to be evolved until it is technically and economically reasonable to use them for a larger scale project. Most commonly used insulation materials are mineral wool, stone wool and polystyrene boards. These materials are recognized all over the world.

External surface

The external surface materials are available in a large variety of different materials, colors and properties. But most importantly wind, snow, rain and also sun should be blocked as much as possible.

Airtight envelope

The airtight envelope is a very important feature in a Passive House Construction. The minimum requirement given by the Passive House Institute, the n_{50} should not be greater than 0.6 h^{-1}. For colder climates it is necessary to minimize this value as much as possible, to prevent unintended heat loss and to avoid moist air entering the building part. The leakage of heated air would have an impact on

[47] Passivhaus Haustagung- Waermedaemmung von Passivhaeusern, 2002

the heating cost while the moisture in the structure could cause fungus. To fix such a failure after the building is constructed would be quite difficult.

> *"Air tightness is not a question whether a construction is massive or light weight. Built Passive Houses using masonry, timber, prefabricated, lost frame with concrete and steel bearing structure have achieved this superior level of air tightness. Sören Peper, a scientist at the Passive House Institute, proved by a systematic field study that n50 leakage rates between 0.2 and 0.6 h^{-1} can reproducibly be achieved today. Careful design and accurate workmanship are the prerequisites to success. Construction details needed to achieve tightness are available for all important joint and envelope penetration situations."*[48]

When using a timber frame construction it is necessary to add an airtight layer (Fig. 21) which is mounted at the warm side of the structure in a way that air leakage does not occur. Manufactures like ICOPAL have a great variety of all kind of fittings suitable for almost every problem[49].

When using a massive concrete structure it is not needed to add such a layer because of the properties of concrete. But where for example the roof joints the wall an air tight joint has to be achieved.

Figure 20: The Airtight Envelope

[48] Passivhaus Haustagung, Air tightness to avoid structural damages, 2006 (http://www.passivhaustagung.de/Passive_House_E/airtightness_06.html)
[49] ICOPAL, Damp-, fugt- og vindspærrer, 2011

Conclusion

A Passive House Standard is not only a building standard, it is a life style. It should become the minimum requirement of every new and renovation projects around the world. The very low energy expenditure for the residents of a Passive House home is one of the main reasons why Passive Houses are so popular, among increasing awareness of importance of sustainability and willingness to contribute in the fight against global warming. But also the very high comfort level due to the ventilation system and the level of highly insulated building parts give an advantage to it.

The Passive House and its standard are already 20 years old, but people still speak about it like it were a new invention. The building regulations in different countries have been evolving throughout the years towards the Passive House Standard and sooner or later this standard will become the minimum requirements for building projects all over the world. The driving force for these changes is the future lack of fossil fuel, high energy cost and global warming, where significant improvements of energy efficiency of buildings is absolutely necessary if global targets are to be met.

Right now the standard of the Passive House is a step ahead of most of other building types. The feasibility of achieving this standard will become easier with time, due to more energy efficient materials and also better knowledge of craftsmen and designers. Therefore constructing Passive Houses in harsh climates will become the normal standard of constructing as in other climate.

In extreme locations like in northern Norway it will be challenging to build a Passive House the way it is done in a moderate climate, but with some minor deviation of the Passive House Standard, it is a feasible option. A very good example of a Passive House in extreme conditions is the Schiestlhaus, which is a perfectly working Passive House in Austria. To make it work a special feature was applied in this building, a wood burning stove with an output of 10 kW of heat. That makes it possible to heat the building in extreme conditions, and of course due to the purpose of the building, it is an emergency dwelling, internal heat gain from occupants and electric equipment is quite low. This kind of feature, a wood burning stove, could be a perfect addition for a Passive House in Norway and other cold places, also because of the tradition of having a fireplace and the sources of firewood in the Nordic countries. But when doing so it is clear that the entire building has to be designed the way that this additional heat source does not cause overheating and the stove would have to be especially adapted for a Passive House. In areas north of the polar circle, where the heating power of the sun is not available for quite a time during the year, the addition of an extra heat source will be an efficient way to keep the construction cost of the building within an affordable range. For a better and deeper knowledge it would be necessary to monitor different Passive House constructions in these areas for at least an entire year. This would help to give a clear result of the actual energy usage.

The cheapest and the most efficient way to achieve a Passive House is to take all aspects and design into consideration already on the drawing board. In a cold climate it is very important to find a suitable location, the right orientation and of course the architectural design of the building. For example it is very important to keep the surface area of the building as small as possible which has a huge effect on the heat loss. Such buildings maybe seem boring to many architects but they are effective and even square and plain buildings can be made interesting.

The amount of insulation needed in colder climates is not the main problem. The building can be designed easily with wall/roof thickness of 800 mm or more. The main problems are the windows, the lack of sunlight and the ventilation system with the heat recovery. The thermal properties of windows will improve in the future, but they will never reach the properties of a wall. So it is important to reduce the window area within a reasonable manner, so that the heat loss will be reduced but the gain of daylight is still efficient enough. In Nordic areas it is even more important to reduce the window area, due to the lack of daylight during the winter months and the amount of daylight in the summer.

The heat recovery of the ventilation system is not efficient enough for extreme cold climate like described earlier and probably never reaches the value of 99% given in table 2. But this has to be compensated with for example an emergency heat source or less window area.

Even when not reaching the exact Passive House Standard in a very cold climate with the 15 kWh/m^2a or the applied value of 20-30 kWh/m^2a as listed in the Passive House Standard, it is still a win- win situation for the house owners with huge savings of running cost and the environment through the low CO_2 emission.

As has been noted, better materials and increased know how will make the achievement of the Passive House Standard easier but that should not be the main factor to reach and certainly not at any price. More important is that the features of a Passive House are applied to every region in the world to save energy. When achieving a low energy building, for example listed in the Danish building regulations, in a very cold climate it would be a huge improvement to a regular building in these areas. But of course the name Passive House could not be used.

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List of Figures

List of Tables