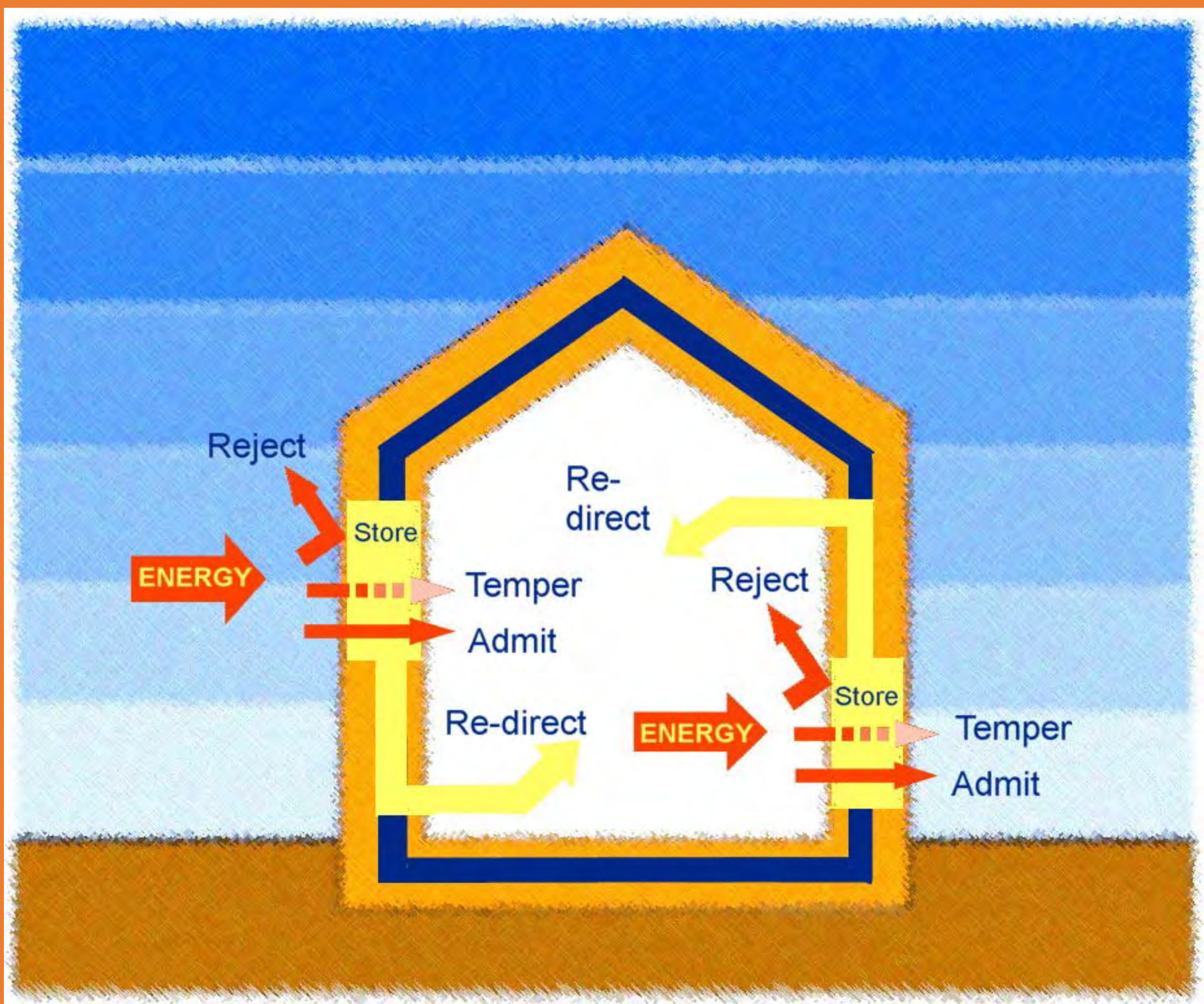
# *Absolute* **passive energy design**

## Achieving passive house level by utilizing hygrothermal properties of wood

**INTERIM REPORT TO PROJECT** helTREnkelt (Simply Wood)

Gaia Lista/Asplan Viak/Treteknisk Institutt/Silvinova, December 2014



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# Foreword

*helTREnkelt* is a Norwegian research and innovation program which began in April 2014 and will extend over 2-3 years. The project is divided into three parts:
1. Establishment of theoretical foundation / hypothesis
2. Field experiments
3. Summary and Conclusions.
The project is led by *Gaia Lista* (Bjørn Berge (part 1) and Dag Roalkvam (part 2 & 3))

The other participants are:
*Asplan Viak* (Arne Førland Larsen, Anne Sigrid Nordby and Per F. Jørgensen)
*Norwegian Institute of Wood Technology* (Kristine Nore)
*Silvinova* (Ola Øyen)
*Sibu/Rodeo Architects* (Henning Sunde)

The project is supported by:
*Hunton Fiber* (contact: Thomas Løkken)
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The report is translated from Norwegian by Asbjørn Warholm. Professional proofreading by Chris Butters.

This is the report for *helTREnkelt* part 1. The main report will be delivered after completion of part 3.

Lista 15.12.2014 Bjørn Berge (head of part 1)

# Summary

The Norwegian authorities aim to greatly reduce the energy consumption in buildings towards 2020. To achieve this the energy requirements of the Norwegian technical construction regulations (TEK) will intensify. In the next revision, all new buildings must meet an energy consumption equivalent to passive house level. (Stortingsmelding 21/2012).

As of today, the so-called *Passivhaus standard* is the only type of solution being considered. The model is based on passive measures in the building form and construction, such as improved thermal insulation, high airtightness and reduced cold bridges. The effect of these measures is however not sufficient, so the buildings are supplemented with technical measures, primarily in the form of a mechanical ventilation system with heat recovery from exhaust air.

The project helTREnkelt examines whether *Passivhaus standard energy level* can be achieved by using exclusively passive energy measures in an *Absolute passive energy design*. As a starting point of helTREnkelt, a range of measures are used, which are currently not included in conventional energy design. One of the most important measures is the utilization of the hygrothermal properties of wood to stabilize the moisture level in the indoor air, and to prevent moisture loads on surfaces and structures.

The *LIMA Pyramid* (see Figure 1) is designed as a planning tool. The process is initiated with an analysis phase which consists of a *functional analysis* and a *climate analysis*. The *functional analysis* is based on the functional cycles in the building, where parallel energy-related characteristics (temperature, humidity, pollution, etc.) are clarified. In the *climate analysis* the exterior loads on the building envelope are mapped, as well as possible future changes due to climate change. In each analysis, energy flows (wind/solar energy/internal gains etc.) in and around the building are identified and an evaluation is made as to whether they should be utilised or prevented/redirected-. Critical parameters are occurrence, strength and frequency. Having established the basis of the analysis, four stages of planning follow, where appropriate measures are chosen from each stage and integrated into the project, forming a holistic energy concept for the building. This in summary is referred as a *Passive measure profile*.

Simulations were conducted for a detached house using the methodology of the *LIMA Pyramid* where the *Passive measure profile* complies with the current norms of indoor air quality in EN 15251. Simulations are made for both Bergen (maritime climate) and Oslo (humid continental climate). The result shows that the detached house meets the heating requirement for *Passivhaus energy level* with a good margin for both localities. It may be assumed that similar results could be obtained for commercial and other types of buildings.

The simulations will be followed up with a test phase where energy-related effects of the use of wood will be documented through field tests at Øvre Sund student housing, which is now under construction in Drammen city.

# Introduction

## Background

The Norwegian authorities aim to greatly reduce the energy consumption in buildings towards 2020. To achieve this, the energy requirements of the Norwegian technical construction regulations (TEK) will become progressively stricter. By the next revision, all new buildings must achieve an energy consumption equal to *Passivhaus level*. (Stortingsmelding 21/2012).

The current regulations, TEK10, state that energy efficiency should be achieved through permanent features of the building envelope, with so-called passive energy design, partly because such measures are considered more robust than solutions based on technical installations. (DiBK, 2013). The *Passivhaus standard* as it has been defined by Norwegian Standards NS3700 and NS3701 is partly developed on the basis of this. A passive house achieves large reductions in net energy requirements by using a range of standardized passive measures, the main ones being improved thermal insulation, high airtightness, energy efficient windows and reduced thermal bridges. The combined effect of these measures is however not sufficient, so a technical installation, primarily in the form of a mechanical ventilation system with heat recovery from exhaust air, is usually installed in the building.

In 2013, the consulting firm Ramboll delivered, on behalf of the Directorate for Construction Quality (DiBK), a study of possible strategies for new technical construction regulations (Smits, 2013). A meeting was held in August of the same year for inputs and discussion regarding this. Although the overall intent of the study is a more technology neutral direction than that of the current regulations, concerns were raised at the meeting that the proposed *Passivhaus standard* could easily end up as current TEK practice, if the strategy is too narrow and follows only one approach:

"The design of the new TEK 15 must not be an obstacle to innovation and innovation"
(National Association of Norwegian Architects).

"AiN is worried about solutions that create hermetically closed buildings and complex technical installations. The requirements must encourage a greater degree of innovation and new thinking within ventilation solutions"
(Architect Firm AiN).

These and similar concerns are further confirmed in various surveys including (IPSOS MMI, 2013) and (Warholm, 2014).

*Arguments for absolute passive energy measures:*

- **Robust.** No moving parts, and independent of energy supply
- **Reduced embodies energy**. A reduction in the use of energy intensive metals and plastic materials
- **User friendly.** Noise-free and adaptable, with reduced monitoring needs. It is also better suited in the case of power failure
- **Cost effective.** Reduces construction and maintenance costs

## The project

The project *helTREnkelt* (Simply Wood) aims to build on the fundamental premise of the technical building regulations TEK10 that measures should in principle be passive. One possible reason why the current passive standard quickly succumbs to the use of technical installations may be the narrow focus on only a limited range of possible passive measures. Others are overlooked, such as adapting the rooms for their intentional functions, and adapting design to the specific local climatic contexts.

*helTREnkelt* presents an alternative methodology for passive energy design based on analyses of function and locality. This opens up for a wider range of energy measures, many of which are not currently included in conventional calculation models. The methodology is applicable for energy planning, thermal climatisation (heating / cooling), lighting, water and equipment use. The measures that are examined in this project are however limited to thermal climatisation.

The effects of using wood are documented especially, primarily the thermal- and moisture-regulating properties of the material.

## Progress and Reporting

*HelTREnkelt* can be considered a continuation of the project *Passive climatisation*, for which Asplan Viak was the project manager (Nordby, 2014). It was delivered to its clients DiBK and the Norwegian Housing Bank in April 2014. It presented a preliminary study of passive energy design. The methodology and measures are developed and expanded in *helTREnkelt*, along with improved documentation of the effects. The project consists of three parts:

> *Part 1 Hypothesis phase*. Development of a theoretical basis through source studies and simulations. This includes planning for field experiments to be conducted at a new building, Øvre Sund Student housing in Drammen (ØSS). This part ends with an interim report.
>
> *Part 2 Experimental phase*. Set up and implementation of the field experiments at the Student housing in Drammen (ØSS).
>
> *Part 3 Synthesis phase*. Analysis of the experimental results. Revisions of methodology and simulations from part 1. Summary and conclusions. This concludes with an Assessment Report.

## Report Part 1

The interim report consists of three main chapters and four appendices. The main chapters present the key results, whilst the appendices provide additional information and documentation.

> *Chapter 1 Method Development*. Presentation of current methodology to optimize utilization of passive energy measures.
>
> *Chapter 2 Building simulation.* Testing the methodology in a residential example. Energy calculations.
>
> *Chapter 3 Plan for testing wood as a passive measure*. Outline of experiments at ØSS.

*Appendix 1 Measures for improved thermal indoor climate.* Review of relevant measures for passive energy design, including documentation and references.

*Appendix 2 Building simulation, complementary*. Detailed review of the residential example, including energy calculations and analyses.

*Appendix 3 Wood as a passive energy measure.* Comprehensive presentation of the benefits of using wood as interior material.

*Appendix 4 Surface treatment of wood.* Relevant surface treatments to protect the hygroscopic and thermal properties of wood.

# 1. Method Development

The *LIMA-pyramid* is designed as an early phase tool to design energy efficient buildings. The purpose is to maximize the utilization of passive energy measures in design, construction and choice of materials. It is expected that this will reduce the need for technical installations.

On the basis of an analysis, there are four stages of planning, where appropriate measures are chosen at each stage and integrated into the project, forming a holistic energy concept for the building project.

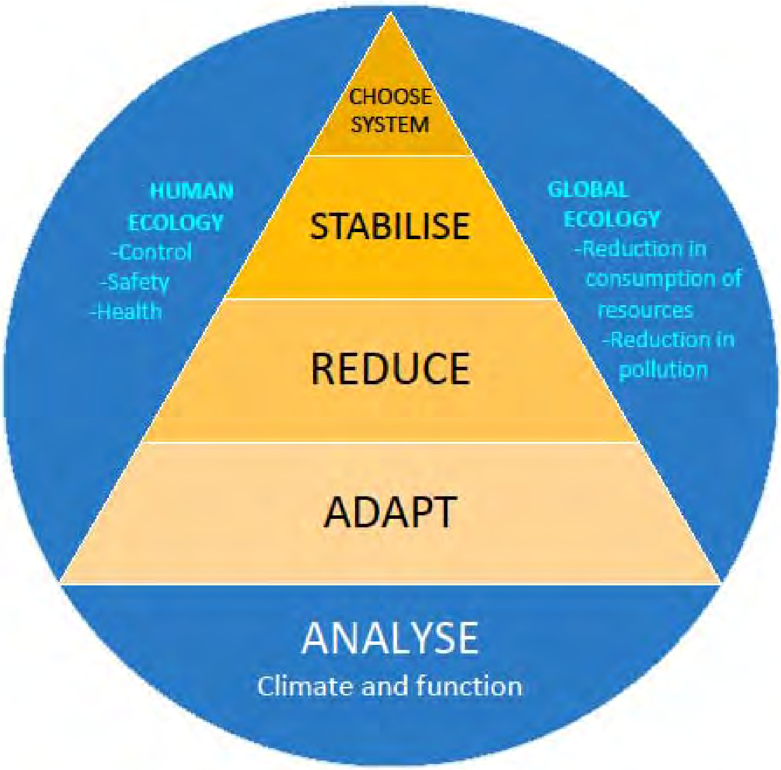


*Figure 1*: *LIMA- pyramid, The tool was named after the international climate meeting in Lima December 2014.*

## The Encirclement

The analysis phase includes a *functional analysis* and a *climate analysis*.

The different functions of a building, and their cycles, are the basis of the *functional analysis.* The analysis addresses energy-related aspects (temperature, moisture, contaminants, lighting levels, etc.) related to these. The *climate analysis* maps exterior loads on the building envelope, including impacts of possible future climate changes.

Energy flows in and around the building are identified in each of the analyses, before being either diverted or utilised in the design, as seen in *Figure 2*. Decisive parameters are incidence, strength and frequency.

*Human Ecology* and *Global Ecology* are applied as guiding premises for all choices made at the various levels in the process.

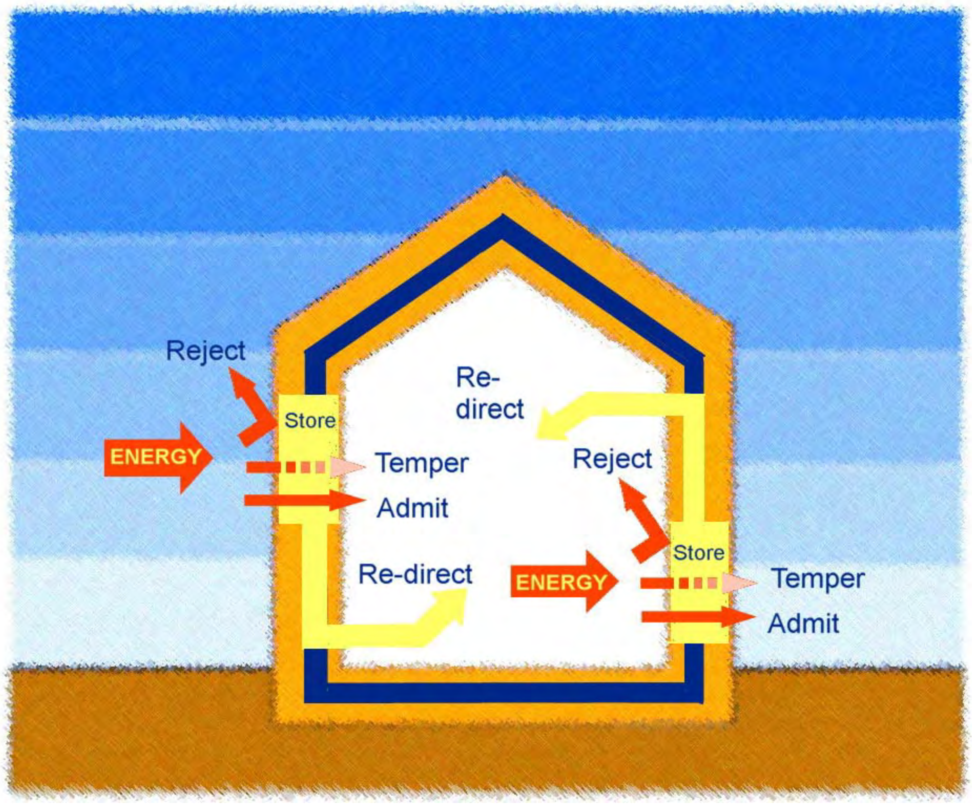


*Figure 2: Model for passive use of energy flows in and around buildings, (adapted from Perino, 2008)*

## The Pyramid

The pyramid is developed on the principle of the Norwegian children's game "This is what you have - This is what is left”, in which a handful of sand is thrown into the air and gathered again alternately with palms up or down. The “sand” which does not end up on the ground, is kept for the next round.

The *LIMA Pyramid* is divided into four steps:

> *1. Adapt*. Measures that can be taken to either utilize, deflect or redirect ambient energy flows and energy related impacts among the different functions, in connection to the exterior environment. For example reusing latent heat from the moisture in the air for heating, or utilization of local wind and air movement for cooling.
>
> *2. Reduce*. Passive measures for further reduction of the energy demand which cannot be solved by adaptation. For example, positioning rooms that require a lower temperature so that they have an external wall, or the use of thermal insulation on interior walls.
>
> *3.Stabilise*. Measures to optimize and predispose the remaining energy flows in relation to the diurnal usage patterns and local climate rhythms. For example, stabilization of room temperature and moisture levels by using materials and spatial design.

*4. Choose system*. Different heating and ventilation systems are then considered to cover the remaining needs, including both for operation and maintenance of the system. For example, ventilation and energy distribution based on natural forces (wind, pressure and temperature differences).

The *LIMA pyramid* can be used to develop passive measure profiles for the following energy demands: *Room heating* and *cooling*, *hot water*, *lighting* and *equipment*.

An evaluation is made for every measure that is implemented, to check for conflicts or synergy effects with measures selected in the earlier steps. After finishing step 3, any interaction effect is rechecked with all selected measures, before a final system is chosen in step 4.

The work in this report is limited to investigating the energy demand for room heating/cooling. Any influence with other energy demands such as for *hot water* and *lighting* will however to a certain extend also be covered.

## Measures

The outline in Table 1 (below) includes measures related to thermal climatisation (heating and cooling) and includes both *direct* and *indirect* measures. The *direct* measures provide direct reductions in heating and cooling needs, whilst the *indirect* measures help lower ventilation needs. The list is limited to the first three steps in the *LIMA Pyramid*, where each step consists of additional sub steps with individual measures. The different measures are categorized with a priority from 1 to 3, for both domestic and non-domestic buildings.  The criteria consist of the following (the basis for the criteria is given in Appendix 1):

*Potential for energy saving.* Whether the effect of the measure is considered significant compared to the extra effort of using energy-intensive building materials.

*Documentation Level.* Whether there is sufficient documentation of good quality, and if the measure can be calculated/simulated.

There will also be a discussion about the sustainability of the measures, whether they are likely to be used or easily disregarded through manipulation by the users. This uncertainty will however apply to most types of energy measures, as is exemplified by large differences in measured energy consumption in otherwise identical low energy and passive energy houses, see inter alia (Kristensen, 2011). Passive measures on the building envelope will initially be considered as more straightforward and robust than technical installations, but some of these too may be misused. Nevertheless, the potential for energy savings will remain, and utilization will ultimately be determined by factors such as understanding, motivation and energy prices.

Some of the measures presented violate current calculations norms in Norwegian Standard  NS 3031. These deviations are substantiated in Appendices 1 and 2, and alternative computations are used instead, mainly IDA ICE (EQUA, 2014). These comply with current climate standards EN 15251.

*Table 1: Overview of measures to reduce the demand for room heating and cooling needs for steps 1-3 in the LIMA pyramid. This includes priorities for domestic and non-domestic buildings. Measures and priorities are elaborated in Appendix 1.*

| | Measure | Principle | Priority domestic building | Priority non-domestic building |
|---|---|---|---|---|
| 1 | **STEP 1 ADAPT** | | | |
| 1-1 | ADAPTING TO FUNCTION | | | |
| 1-1-1 | Co-localisation of rooms with equal temperatures | Co-localisation of rooms with the same temperature needs. | 1 | 1 |
| 1-1-2 | Utilisation of internal surplus heat | Utilisation of surplus heat from people, equipment and different processes. | 2 | 2 |
| 1-1-3 | Utilisation of latent energy from water vapour | Utilisation of latent energy stored in water vapour from showering, clothes drying, cooking and exhalation etc. | 2 | 2 |
| 1-2 | **ADAPTATION** TO LOCAL CLIMATE | | | |
| 1-2-1 | Reduction of the pollution load | Reducing pollution levels from the incoming air supply | 1 | 1 |
| 1-2-2 | Reduction of wind and air streams | Reducing the effect from local wind loads | 1 | 1 |
| 1-2-3 | Utilisation of wind and air movements | Utilisation of the wind for cooling and operation of natural ventilation | 2 | 2 |
| 1-2-4 | Solar shading | Prevent overheating | 1 | 1 |
| 1-2-5 | Utilisation of solar radiation | Used for room heating/cooling, and operation of exhaust systems (solar chimneys) etc. | 1 | 1 |
| 1-2-6 | Reduction of temperature differences | Reduced temperature differences through the climate screen | 2 | 2 |
| 1-2-7 | Utilisation of temperature differences | Cold night air for cooling, operation of exhaust, stack effect etc. | 1 | 3 |
| 1-2-8 | Utilisation of stable ground temperature | Utilisation of stable ground temperature for heating/cooling | 1 | 3 |
| 1-2-9 | Utilisation of air humidity | Utilisation of moisture in outdoor air for cooling | 3 | 3 |
| 1-2-10 | Utilisation of differences in gas pressure | Differences in gas pressure through the climate screen is used to ventilate moisture and pollution. | 3 | 3 |
| 2 | **STEP 2 REDUCE** | | | |
| 2-1 | REDUCED CLIMATE SCREEN | | | |
| 2-1-1 | Differentiated temperature levels | Temperature levels based on the function of the rooms | 1 | 1 |
| 2-1-2 | Reduced external surface area | Compact building form | 1 | 1 |

| | | | | |
|---|---|---|---|---|
| 2-1-3 | Unheated rooms position to external walls | Rooms with function(s) that have no specific temperature requirement are positioned against the external wall | 1 | 1 |
| 2-2 | IMPROVED CLIMATE SCREEN | | | |
| 2-2-1 | Sealing of external surface | Airtight layer for reduced infiltration and air leakages. | 1 | 1 |
| 2-2-2 | Thermal insulation of the building envelope | Reduced heat transmission by using building materials with improved insulation. | 1 | 1 |
| 2-2-3 | Heavy and/or hygroscopic materials as thermal buffer | Heavy materials used as thermal buffer to create a phase lag for heat penetration during the summer. | 2 | 2 |
| 2-3 | IMPROVED INTERNAL PARTITIONS | | | |
| 2-3-1 | Thermal insulation of internal walls | Reduced heat transfer between adjacent rooms with different temperature needs. | 1 | 1 |
| 2-3-2 | Air tightening of internal walls | Reduced heat transfer between adjacent rooms with different temperature needs. | 1 | 2 |
| 2-4 | REDUCED TEMPERATURE LOAD | | | |
| 2-4-1 | Reduced internal surplus heat | Selection of equipment etc. for reduced internal loads. | 3 | 3 |
| 2-5 | REDUCED TEMPERATURE LEVEL | | | |
| 2-5-1 | Surfaces with low thermal conductivity | Reduced temperature need as a result of increased radiation temperature from interior surfaces | ? | ? |
| 2-5-2 | Improved user control | The users tolerance for temperature increases due to understandable and easily accessible user control | 1 | 1 |
| 2-6 | REDUCED HUMIDITY LEVEL | | | |
| 2-6-1 | Reduce moisture production | Measures to reduce moisture production from internal sources | 3 | 3 |
| 2-7 | REDUCED POLLUTION LEVEL | | | |
| 2-7-1 | Building with very low pollution level | Thorough use of very low emitting materials | 2 | 1 |
| 2-7-2 | Photo catalytic degradation of pollutants | Degradation of air pollution through photo catalytic oxidation | 3 | 3 |
| 2-7-3 | Air purification through plants | Biodegrading of airborne contaminants | 3 | 3 |
| 2-7-4 | Materials that bind air contaminants | Permanent binding of air contaminants in reactive materials | | |
| 3 | **STEP 3 STABILIZE** | | | |
| 3-1 | TEMPERATURE STABILIZATION | | | |
| 3-1-1 | Temperature buffering room design | Utilisation of natural stratification, usually achieved by increased ceiling height | 2 | 1 |
| 3-1-2 | Temperature buffering materials | Exposed material surfaces with temperature regulating properties | 1 | 1 |
| 3-2 | HUMIDITY STABILIZATION | | | |
| 3-2-1 | Moisture buffering materials | Exposed surfaces with moisture regulating properties | 1 | 1 |

| | | | | |
|---|---|---|---|---|
| 3-3 | STABILIZATION OF AIR CONTAMINANTS | | | |
| 3-3-1 | Pollution buffering room design | Utilisation of natural stratification, usually achieved by increased ceiling height | 2 | 1 |
| 3-3-2 | Pollution buffering materials | Wood panelling that stores airborne contaminants | 2 | 2 |

## Using wood as a passive measure

Passive energy measures include the design of the building and/or the use of materials. Design measures consist of how best to design the site layout, floor plan, building form and construction. The use of material focuses on how to utilise the properties of materials, such as their weight, density, texture, porosity and hygroscopicity.

*Wood* is of particular interest in this context. It is hygroscopic, meaning that it has an open pore structure that quickly takes up moisture from the indoor air when the humidity rises and release it when the air gets dryer. Wood will always seek to achieve equilibrium with its surroundings.

In order to utilise this, the wood surfaces should be either untreated or treated with a vapour permeable surface treatment for effective moisture regulation, (see Appendix 4)

Wood can be used as an active material in the following types of measures:

- 1-1-3 *Utilisation of latent energy from water vapour*
- 2-5-1 *Surfaces with low thermal conductivity*
- 3-1-2 *Temperature buffering materials*
- 3-2-1 *Moisture buffering materials*
- 3-3-2 *Pollution buffering materials*

Measures 1-1-3, 3-1-2 and 3-2-1 are the most prevailing based on the documentation that currently exists. All these are related to the moisture regulating properties of wood. A more detailed description of the potential is given in Appendix 3.

# 2 Building simulation

## Introduction

A simulation of a detached house located in Bergen (maritime climate) and Oslo (humid continental climate) has been carried out. The basis of the design and development is the methodology in the *LIMA pyramid*.

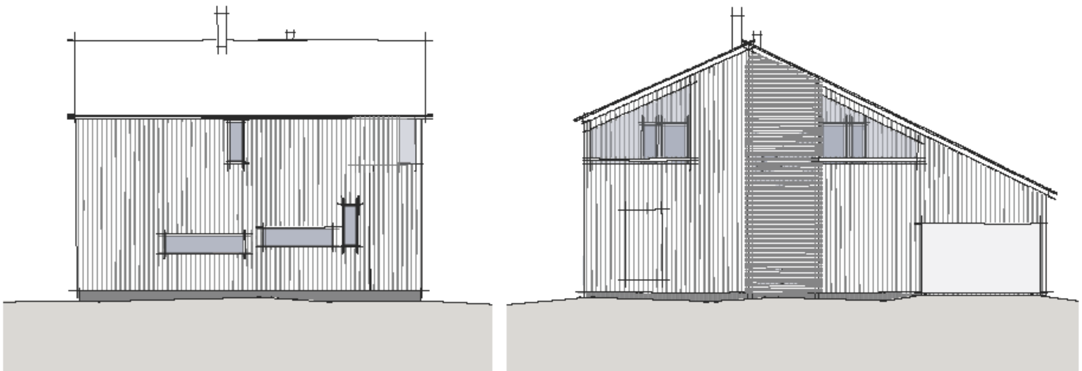

*Figure 3: Building model designed for the harsh maritime climate in the Bergen area. Façade east (left) and façade north (right).*

It is claimed that buildings designed according to the principles of the Norwegian Passivhaus standard NS 3700 will have a major impact on energy consumption for heating and ventilation. The primary goal of the simulations in this report is to examine whether the same energy efficiency can be achieved in buildings designed and operated using the principles of the *LIMA Pyramid*. The simulation will also be used to try to identify the effects of various passive measure profiles, as well as whether extended use of passive measures could improve the energy efficiency for conventional passive houses with mechanical ventilation.

The model used in the simulations must be considered as a simplified building, where the need to examine and elucidate the various measures is given greater weight than architectural aspects. Plan solution, universal design, daylight principles, etc. are nevertheless in compliance with the *Requirements for construction* given by Norwegian technical construction regulations (TEK).

## Analyses

The functions of the building and the impact from the local climate on the building's envelope are analysed in this study. The analysis is then the basis for planning the building.

The functional analysis maps the different rhythms of building use and their consequences, including production of moisture and requirements for temperature and ventilation. The climate analysis maps the local climatic conditions, that is, the occurrence, strength and frequency of temperature, humidity, wind, precipitation and solar radiation as well as ambient pollution.

The purpose of the analysis is to identify internal and external energy flows which could be utilized, converted - or diverted (see Figure 2).

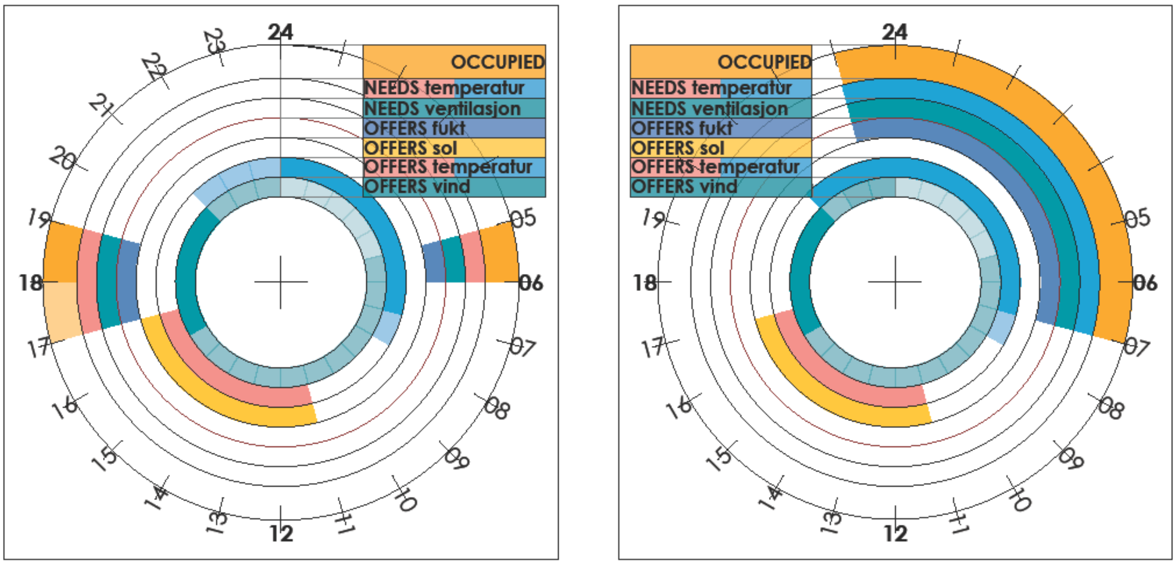


*Figure 4: Examples of “rhythm clocks”. Kitchen chart (left) and bedroom chart (to right). Similar “rhythm clocks” are planned for the varied functions of the building.*

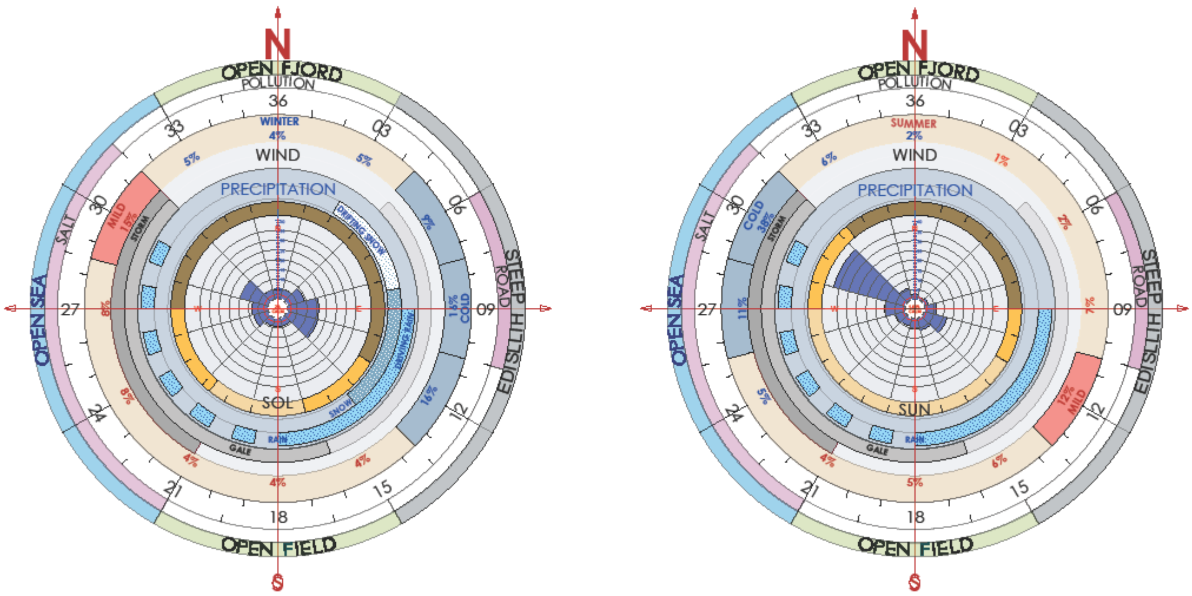


*Figure 5: Climate rose winter (left), and summer (right) for weather exposed Bergen locality.*

## Passive measure profile

Passive measure profiles for Oslo and Bergen were prepared based on the analysis. *Table 2* presents relevant measures for steps 1, 2 and 3 in the *LIMA Pyramid*. The measures were taken from table 1 in Chapter 1 (elaborated in Appendix 1). The use of wood in particular is emphasised, and is described in more detail in *Appendix 3*. Relevant cost effective measures that are well documented and within the norm of conventional floor plan and design, were prioritised for this particular building.

The table below also contains some measures that were not included in the simulation, as they might have been controversial and difficult to simulate. Measures related to climatisation against wind loads were not simulated to achieve a comparison between Oslo and Bergen climate.

*Table 2: Simulation of detached house. Passive measure profiles for steps 1, 2 and 3 in LIMA pyramid with an overview of measures that were included in the simulations, as well as appropriate measures that were not included.*

| | Simulated measures | Non-simulated measures |
|---|---|---|
| *1-1-1* | *Co-localisation of room with equal temperatures* | |
| | The functions were co-located in groups with corresponding temperature requirements. Thus semi-heated bedrooms were gathered on the $1^{st}$ floor (i.e. upstairs), while the warmer core consisting of the living room, kitchen and bathroom was located on the ground floor. | |
| *1-1-2* | *Utilisation of internal surplus heat* | |
| | | NS 3031 gives no opportunity to credit heatloss from domestic water heating. The residential model was adjusted to utilise this heat, by placing the water heater in the hallway of the $1^{st}$ floor (i.e. buffer room with no temperature requirement). The heat is passed to adjacent rooms by transmission. |
| *1-1-3* | Utilisation of latent energy from water vapour | |
| | Energy contained in water vapour will contribute to space heating by utilising surfaces with hygroscopic wood cladding in combination with natural ventilation cycles. In the bathroom, this will primarily relate to the use of showers, whilst in bedrooms and other living rooms it will revolve around utilising the energy stored in moist air from breathing. | |
| *1-2-2* | *Reduction of wind and air streams* | |
| | | The Bergen alternative is located in a windy locality. Shielding against dominant winter winds from the east and northwest is achieved by good site design and adapted building form, and effective external shielding. The external shielding would, under most climate conditions, limit the temperature fluctuations behind the shield to between 1 and 6 degrees in the |

winter. Heat loss by radiation from the building will also be reduced.

| 1-2-5 | *Utilisation of solar radiation* |
|---|---|

A *conditioning room* (glass chamber) was introduced to preheat the incoming air via solar radiation, (see Appendix 3 for details). The *conditioning room* also reduced transmission losses from any adjacent rooms. Plants and hygroscopic surfaces temporarily store energy for the user phase which occurs after sunset. The incoming solar radiation can be used in living rooms to dry out moist surfaces to prepare them for the utilisation of latent heat in the period of use after sunset.

| 2-1-1 | *Differentiated temperature levels* |
|---|---|

Customized temperature levels were established for the building, and adjusted for the function of the individual rooms. E.g. the temperature in the bedrooms was set to 14°C as the lowest limit, this is ideal for indoor climate according to the Norwegian Institute of Public Health (Jansson, 2013). This was achieved by ventilating rooms separately, as well as locating wardrobe and study spaces in separate compartments. Toilets and bathrooms were also separated for better adapted temperature levels.

Porch, coat wardrobe, clothes drying, staircase and hallways are removed from the heated zone. These rooms have no temperature requirements, although they are normally included in heated zone calculations.

| 2-1-2 | *Reduced external surface area* |
|---|---|

Design measures were implemented to reduce the external surface area for the heated zone.

| 2-1-3 | *Unheated rooms position to external walls* |
|---|---|

75% of the wall area of the heated zone is shielded from the exterior with unheated rooms.

| 2-2-1 | *Sealing of external climate screen* |
|---|---|

The same air tightness is achieved as a passivhaus following NS3700. Minor leakage was accounted for in the ventilation rate.

| 2-2-2 | *Thermal insulation of the building envelope* |
|---|---|

U-values and normalized thermal bridge values are as in a passivhaus following NS3700.

| 2-3-1 | *Thermal insulation of internal walls* |
|---|---|

Interior walls and joists in heated rooms are thermally insulated. The thicknesses vary in function of the temperature requirements. Bedrooms are mainly heated by transmission losses from warmer adjacent rooms.

| 3-1-2 | *Temperature buffering materials* |
|---|---|

Hygrothermal effects in internal wood panelling are used to temporarily store and regulate the temperature from incoming solar radiation.

| 3-2-1 | *Moisture buffering materials* |
|---|---|

Internal wood panelling with hygrothermal effects is used to temporarily store and regulate the temperature from incoming solar radiation.

Heating and ventilation solutions are addressed at step 4 of the *LIMA Pyramid*. The type of heating system for this project was not considered. Natural ventilation was chosen as the preferred ventilation method (see description of the principle in Danish Standard DS 447/2013). Several of the measures in steps 1, 2 and 3 helped to improve indoor air quality and reduce the ventilation requirements. This enabled the use of differentiated ventilation levels. Overall ventilation level corresponded to the recommendations in EN 15251, where living rooms were ventilated with 26 $m^3$/h per person (7 l/s) during periods of use and a minimum ventilation of 0.18-0.36 $m^3/m^2h$ (0.05 to 0.01 l /s m2). Bedrooms were separately ventilated with 26 $m^3$/ h per person. Demand controlled mechanical exhaust over the kitchen cooker was included in the ventilation loads.

The accommodation listed in wood and functions provided over two floors have a total gross internal area of 180 $m^2$, including the garage. 115 $m^2$ of this area is heated. The living room is fitted with glass area of the order of 25-30% of floor area. Wood fibre was used for thermal insulation. Interior walls and ceilings are wood panelling with diffusion open surface treatment.

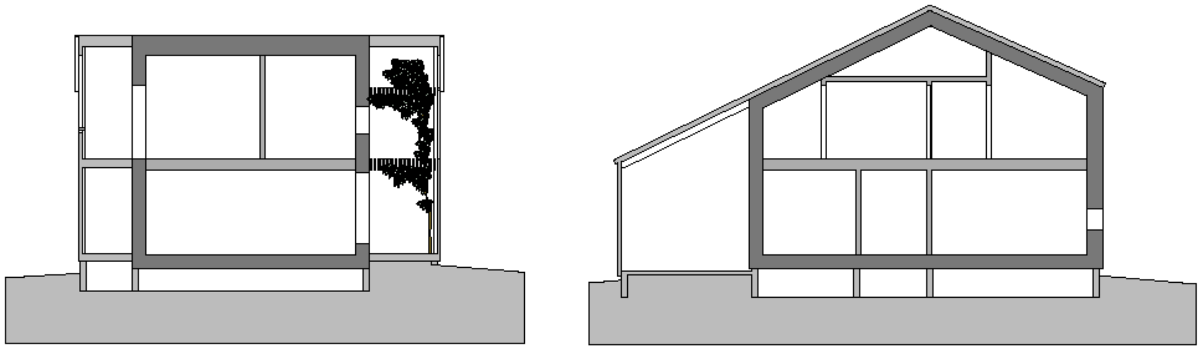

*Figure 6: Building model for Bergen locality, with section A-A (left) and section B-B (right).*

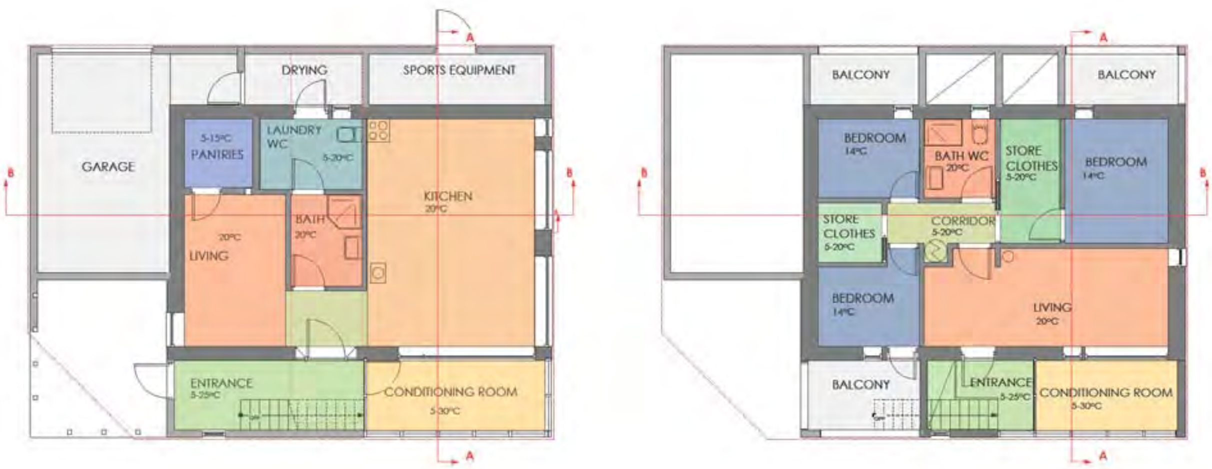


*Figure 7: Building model for Bergen locality with ground floor (left) and plan 1st floor (right). Temperature levels differentiated by functions. Reduced exposed outer surface in heated rooms. Heated room (see Appendix 3) facing south. Main WC as a separate room. Unheated rooms used as a shield against dominant winter winds from northwest. Living rooms in both floors with glass area more than 25% of the floor area.*

## Simulation results

The simulations show that energy consumption at *passivhaus level* is achieved easily by implementing appropriate passive energy design measures from the *LIMA pyramid*, see Table 3 below. This applies to both Oslo and Bergen climate.

Simulations and the premise for calculations, as well as various combinations of measures with and without mechanical ventilation, are further elaborated in *Appendix 2*.

*Table 3: energy consumption data for heating and fans in the building models with Absolut Passive Energy Design. Calculated with IDA ICE (4.6.1.) for the Oslo and Bergen climate*

| Models | Net energy use heating [kWh/m²/year] | Net energy use fans [kWh/m²/year] | Total net energy use [kWh/m²/year] |
|---|---|---|---|
| *Reference models:* | | | |
| Passivhaus level after NS3700, Oslo climate | 22,9 [1)] | 4,5 [2)] | 27,4 |
| Passivhaus level after NS3700, Bergen climate | 22,3 [3)] | 4,5 | 26,8 |
| *Results* | | | |
| Absolut passive energy design, Oslo climate | 20,3 [4)] | 0,6 [6)] | 20,9 |
| Absolut passive energy design, Bergen climate | 16,1 [5)] | 0,6 | 16,8 |

*Notes*

1) For a residential building of 115 m² GIA. Oslo Climate. Annual mean temperature 6.1 ° C, (Kvande, 2012)
2) No requirements. Estimates ordinary energy use, including demand-controlled exhaust in kitchen.
3) For a residential building of 115 m² GIA. Bergen Climate. Annual mean temperature ≥ 6.3 ° C, (Kvande, 2012)
4) Corresponds to APM 3 in Table 4, Appendix 2
5) Corresponds APM 4 in Table 4, Appendix 2
6) Natural ventilation with demand controlled mechanical exhaust in the kitchen

The result indicates that residential buildings can reach the requirement for *passivhaus level* without the use of technical installations. This relationship may be further enhanced when future energy requirements for residential buildings will require cooling due future climate change. Many of these passive measures will make it easier to maintain a lower temperature in residential buildings through future heat waves.

It can be assumed that similar results could be achieved in other building types. In this case, passive measures to reduce cooling demands could achieve exceptional results through temperature buffering. Moisture loads are normally higher in schools and other assembly rooms compared to residential buildings, meaning that the moisture regulating properties of materials would be of even greater benefit. The commercial sector also sets stricter requirements for reduced air pollution, which can equally be met by carefully chosen materials as well as passive buffering measures.

# 3 Plan for testing wood as a passive measure

## Introduction

Results from the building simulation indicate that an active use of exposed wood surfaces will provide significant contributions in a passive energy saving strategy. To further increase the knowledge, *helTREnkelt* Part 2 will consist of field experiments which will take place in the upcoming student housing being built in Drammen (Norway). The apartments belong to Buskerud student welfare organization (Sibu) and will consist of 250 studio apartments.

The building project was designed by Rodeo Architects, and construction work commenced in autumn 2014. The load bearing structure is solid wood, and will be exposed along the wall and in the ceiling of each room. The Passive house standard is used as the basis for the energy planning.

*Figure 8: Øvre Sund Student housing in Drammen, Rodeo Architects*

## Field experiments

The field experiment aims to document the hygrothermal properties in relation to its humidification properties within the framework of stochastic (random but statistically calculable) patterns in a residential situation. Any influence on ventilation and heating will be documented. The investigations are limited to the effects achieved by utilizing the latent energy from water vapour (*Measure 1-1-3*), temperature buffering (*Measure 3-1-2*) and moisture buffering (*Measure 3-2-1*).

If possible it is also desirable to further investigate any relation to user control and user preferences.

*Figure 9. Studio apartment at Øvre Sund Student housing, Rodeo Architects*

## Implementation

The aim is to build 40 single studio apartments. 20 will have full hygroscopic capacity, and 20 will have reduced hygroscopic capacity (because the wood surfaces are temporarily covered with painted plates). Within each group a representative sample of different solar exposure will be planned. The solar radiation would contribute significantly to dehydration of stored moisture.

All flats will be equipped with background ventilation at low level (equivalent to the dwelling simulation in Chapter 2). The airflow will be regulated by temperature and CO2 concentration and will be mechanically ventilated during the user phase. Moisture is temporarily stored in the materials, and is later flushed out by mechanical ventilation. Exhaust from the bathroom is manually controlled with a switch that initiates 10 minutes of mechanical ventilation.

The studio facility will initially be provided with a central energy management system (BEMS) which makes it possible to log ventilation levels with high accuracy. The apartments will be equipped with sensors that log surface moisture and temperature, air speed and heat loads from electrical equipment etc. Values will be collected 60 minutes per hour/24 hours per day over a test period of approximately 6 months.

## Simulation

A preliminary calculation of the energy saving potential in a single room was carried out with the simulation tool WUFI (Fraunhofer Institute).

Two alternative designs have been investigated: a) *The control option* in which the bathroom was equipped with tiles and the rest of the apartment was with painted plaster surfaces, and b) the *hygroscopic option* in which the ceiling and two-thirds of the walls are clad with untreated spruce (Norwegian Spruce II WUFI database). The remaining walls are in both cases covered with cabinets, mirrors, pictures, et cetera, which restrict the access to wall surfaces.

The effect of different orientations, with a window facing east or towards southwest, was also investigated.

The calculations included the complete moisture dynamic throughout the apartment, except the latent heat from showering. The latent heat from showering would have a marginal impact on the energy use, but would contribute greatly to the comfort in the bathroom which operated at a lower temperature during the night.

The simulation results show that the hygroscopic alternative reduced the energy consumption for space heating to 5-7% below the passive house level, with flats orientated towards southwest achieving the lowest energy consumption.

# Appendix 1 Measures for improved thermal indoor climate

The following pages consist of short briefings on the different measures that are used for heating and cooling for the first three steps in the *LIMA Pyramid*. Each measure is described separately and is presented with its potential, challenges and synergy effects on other measures, and relevant documentation. On this basis preliminary priorities are set from 1 to 3 for both residential and commercial buildings. The priorities form the basis of the selection of measures in the simulations in Chapter 2.

## Step 1 ADAPT

*Utilise or derive energy from the different functions of the building, and from interactions with the external environment.*

### 1-1 ADAPTING TO FUNCTION

#### *1-1-1 Co-localisation of room with equal temperatures*

By co-locating rooms with equal or adjacent temperature requirements, the internal heat transfer between rooms is limited.

**Potential:** The measure reduces both heating as well as cooling demands. The potential is greatest in dwellings where an extensive distribution of rooms at different temperature zones is possible. The effect can also be achieved in commercial buildings via co-located entrances, pedestrian areas, storage areas, technical rooms, stairs and unheated lightwells.

**Interactions**: No likely conflicts with other measures, but must be considered in conjunction with *2-1-3 Unheated rooms position to external walls*, *2-3-1 Thermal insulation of internal walls* and *2-3-2 Air tightening of internal walls.*

**Documentation:** The measure is included in the sketch plan of the building and is calculated through simulation. An energy calculation may result in conflict with NS 3031 which doesn`t support any calculation of heat or diffusion transfer between different computational zones. Residents are considered as one zone.

**Priority:** 1 for both residential and commercial buildings.

#### *1-1-2 Utilisation of internal surplus heat*

Lighting, technical equipment, hot water and people emit excess heat to the interior. This can, in principle, be utilised for space heating but requires that the sources are placed in proximity to features that can utilise this heat without requiring any form of cooling.

**Potential**: NS3031 allows excess heat from lighting and people, and a considerable part of equipment, to be credited. Heat contribution from water heaters and hot water pipes is, in general, not calculated as usable, since they are normally located in rooms where the yield is quite low or in rooms where they will contribute to overheating in the summer period. A better utilisation could be achieved by customizing the location, for example in a hallway with high tolerance to temperature changes (buffer space). It is possible that 50% of the approximately 4.6 kWh annual heat per litre of HW cylinder capacity lost from a water heater could be saved, see (Bøhm, 2009).

**Interactions:** The measure must be considered with *3-1-1 Temperature buffering room design*, *3-1-2 Temperature buffering materials and 1-1-3 Utilization of latent energy from water vapour.* The latter may conflict with the localisation of a water heater in the bathroom, as supplied air to this room is normally providing a sufficient temperature level.

**Documentation:** Calculation methods are in general standardised and based on operation times and loads according to NS3031, and do not include the potential from customised adaptations. If such measures are to be included they should be specially simulated.

**Priority:** 2 for both residential and commercial buildings.

### *1-1-3 Utilisation of latent energy from water vapour*

There are a number of processes in a house in addition to exhalation that produce water vapour, including showering, clothes drying, cooking and green plants respiration. Water vapour contains bound energy (latent heat). This energy can be recovered by condensation in hygroscopic surface materials instead of being discharged through the ventilation exhausts. The process will raise both the air temperature as well as the surface temperature of the material. The measure must be adapted to the user cycle with the possibility of evaporation of stored moisture outside the time of use. The reverse process can be used for cooling.

**Potential:** The measure will help to reduce energy consumption for heating and cooling for residential and other types of buildings where moisture is emitted to the indoor air. Commercial and other buildings will primarily utilise this effect in schools and community halls but will require a customised procedure with preheating of the premises.

**Interactions:** Must be considered together with measures *1-2-5 Utilisation of solar radiation*, *3-1-2 Temperature buffering materials* and *3-2-1 Moisture buffering materials*

**Documentation:** The effect is partly documented in (Korsnes, 2012) and (Brueckner, 2013). It can be simulated and calculated in IDA ICE or similar software. The effect is not included in NS 3031, with the exception of heat gains from people.

**Priority:** 2 for both residential and commercial buildings.

*See an example of using wood in bathrooms in Appendix 3.*

## 1-2 ADAPTATION TO LOCAL CLIMATE

### *1-2-1 Reduction of the pollution load*

A building will be exposed to local pollution from road traffic, industry, pollen and so on. This can affect the ventilation conditions by limiting the opportunities for natural ventilation, thus increasing contamination and the need for filtration with mechanical ventilation. Pollution loads can be diminished, or in some cases completely eliminated by utilising local wind conditions, adapting the building to the site, landscaping the surrounding terrain, and by actively using vegetation. Customising the position of air inlets and windows used for ventilation can also help to reduce the intake of contamination.

**Potential:** The measure will be particularly relevant in urban areas, and will apply to all building types. The measures has a potential to save energy, by making it easier to use natural ventilation and natural cooling, as well as it will improve the performance in mechanical ventilation systems.

**Interactions:** Must be viewed together with measures *1-2-3 Utilisation of wind and air movements*

**Documentation**: The measure is well documented, such as in (Robinette, 1972) and (Bolund, 1999).

**Priority:** 1 in both building categories, but will depend on the conditions of the local building site and its climatic situation.

### *1-2-2 Reduction of wind and air flows*

Customised location and shielding of a building can partly limit the building's heat loss by reducing infiltration, and partly as a result of increased temperature of the air in the zone between the building and external shielding of vegetation, fencing and similar. The effect can be enhanced by adapting the building site, setting up wind fences and vegetation, and an active plan for deposition of snow. Wind screens directly on the building itself can also be erected. Infiltration loads can additionally be diminished by reduced building height, as well as various shape and structural measures to balance the pressure and manage the turbulence. The shielding would also in the summer period curb evaporation from the surroundings and thus reduce the need for cooling during dry periods.

**Potential**: The shielding stabilizes the temperature in the microclimate around the building. The ambient temperature will, depending on the general temperature and wind speed , vary 1 to 6 degrees above the temperature outside the shielding (Robinette, 1972), enabling substantial reductions in heat loss. Reduced infiltration will be of great importance for buildings in windy locations. The total potential will depend on local wind conditions.

**Interactions:** Must be seen in conjunction with measures *1-2-6 Reduction of temperature differences*. Must be planned with relation to *1-2-3 Utilisation of wind and air movements* and *1-2-4 Solar shading.* The effect will be reduced by increased use of the measure *2-2-1 sealing of external climate screen*

**Documentation**: Measures for wind shielding are included in the energy calculations in NS 3031 with a specific shielding factor. The calculation however only considers impact on heat loss due to infiltration. Reductions due to increased ambient temperature require individual simulations. The effect of wind shielding is documented in (Robinette, 1972), (Børve, 1987) and (Olgyay, 1963).

**Priority:** 1 for both building categories, but depends on local climatic conditions.

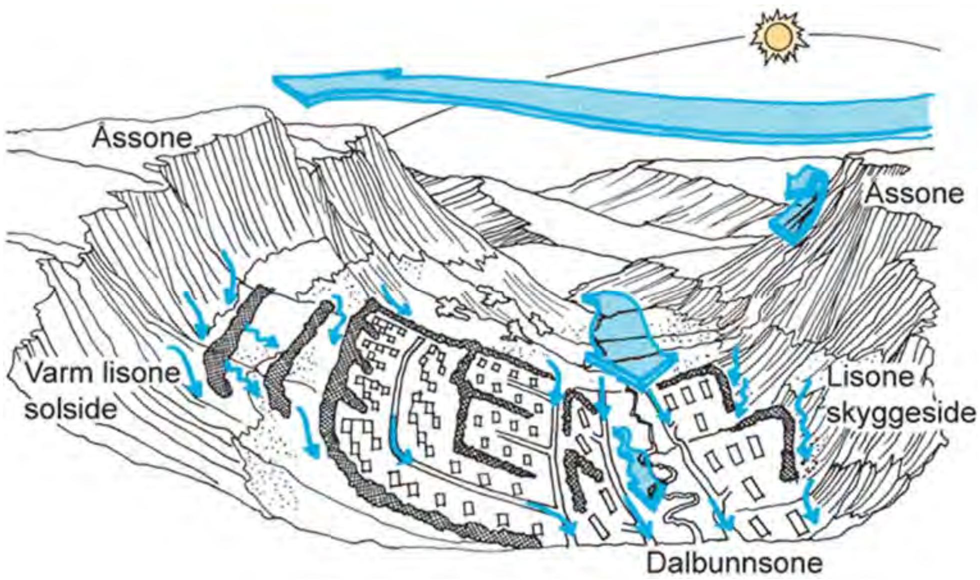


*Figure 10: Measures for shielding against wind loads in a valley, from (Thiis 2005).*

## *1-2-3 Utilization of wind and air movements*

Pressure differentials based on wind and air movements may assist cross ventilation through windows. The different pressure conditions around a building can be controlled via design measures for optimal temperature adjustment of the incoming air, and for direct cooling.
**Potential:** Wind conditions will vary from place to place, but will in the coastal zone be very significant with only 5-10 windless days a year. Wind loads in valleys will be relatively stable and predictable, and will in such areas be a reliable driving force for natural ventilation, as well as simultaneously helping to reduce the cooling demand.
**Interactions:** Must be planned in relation to *1-2-2 Reduction of wind and air streams* and *1-2-4 Solar shading.*
**Documentation:** Operation of ventilation systems through natural forces provides direct savings in electricity consumption. Energy effects of this are not included in conventional energy calculations, but is well documented such as in (Haw, 2012) and (Allard, 1998).
**Priority:** 2 for both building categories, when using natural ventilation.

## *1-2-4 Solar shading*

Solar radiation can lead to overheating of the interior which can be prevented with custom window placement, shading measures on the building body (glass with sun protection factor - SPF, blinds, shutters etc.), vegetation and terrain-related measures. Heating and drying of the surroundings, such as in vegetation and asphalt, can lead to overheating due to the reduced opportunity for cooling by airing through the windows. Drying may also lead to increased dust formation. Vegetation and adapted materials on different surfaces are important measures to use here.
**Potential:** Adapted measures for reduced irradiance loads have a considerable potential in all types of buildings to reduce the need for cooling.
**Interactions:** Solar shading on the building may contribute to an increased need for artificial lighting. It may also conflict with measures *1-2-5 Utilisation of solar radiation* and must be viewed together with measures *3-1-2 Temperature buffering materials* that will reduce or prevent overheating.
**Documentation:** These measures that are taken on the building body are well documented and are included in conventional energy calculations in NS 3031. Shielding factors for vegetation, terrain and nearby buildings are also included.
**Priority:** 1 for both building categories. The perspective for residential buildings is that cooling demands will increase due to expected climate change.

## *1-2-5 Utilisation of solar radiation*

Solar radiation can contribute to heating during the spring and autumn, and to some extent through the winter. This requires that window positions, dimensions, and SPF are customized for the function of a given room, and appropriate materials are used to store the daytime heat for later use. Solar radiation can also be utilised for cooling of incoming air through evaporation processes, as well as enhancement of natural ventilation in solar chimneys. Solar heating of outdoor areas will reduce the heat loss from buildings. This can be improved by using vegetation and surfaces of materials that can absorb and store the energy.
**Potential:** The potential for additional room heating is significant in all building types, albeit to a less extent for buildings with great internal loads.
**Interactions**. The effect can be improved by using materials with buffer capacity in the interior. The process takes place through direct heat absorption in the materials, or by dehydration/discharging of hygrothermal mass (interior claddings) that will later emit heat again through moisture absorption in the

evening. See measures *3-1-2 Temperature buffering materials.* The effect of the measure may conflict with measures *1-2-4 Solar shading.*
**Documentation**: The effect of solar radiation is included in NS 3031. Improved utilisation of buffer materials however are only to a small extent considered *in NS,* suggesting there is potential for a larger portion of available solar energy to be utilized, while the risk of overheating is simultaneously reduced. For documentation of utilizing solar energy for cooling, as well as a driving force for ventilation systems, see (Gontikaki, 2010) and (Allard, 1998).
**Priority:** 1 for both building categories.

### *1-2-6 Reduction of temperature differences*

Trees, terrain and other construction in close proximity will contribute to a reduction of the radiation loss from the building. Avoiding or diverting cold air flows around a building and preventing cold air accumulating will reduce the winter heat loss. Vegetation and materials with good moisture and temperature regulating properties can be used to reduce the demand for cooling during summer.
**Potential:** Reduction of temperature differences will give direct effect on the energy consumption of all building types, especially at inland sites where wind loads are less critical.
**Interaction:** Must be carried out in conjunction with *1-2-2 Reduction of wind and air streams*. Conflicts may occur with *1-2-7 Utilisation of temperature differences.*
**Documentation:** Not included in rules for conventional energy calculations, but is well documented in (Robinette, 1972) for example. It can be simulated.
**Priority:** 2 for both building categories.

### *1-2-7 Utilisation of temperature differences*

Cold night air can be used to cool the building in the summer season, but such an approach requires the potential to store heat generated during the user period. Temperature differences are a reliable source for powering natural ventilation by stack effect during the autumn, winter and spring.
**Potential:** Cooling with night air will reduce the energy consumption, and is applicable for many commercial buildings, and also to some extent in residential buildings. Temperature differences are in quite many cases sufficient to drive natural ventilation, and must be regarded as more reliable than wind and solar heat.
**Interaction:** The effect of night cooling will be enhanced in combination with *3-1-2 Temperature buffering materials.*
**Documentation:** The cooling aspect is not included in conventional energy calculations, but is well documented in (Robinette, 1972). The additional contribution it gives to drive natural ventilation can be calculated.
**Priority:** 1 for both building categories

### *1-2-8 Utilisation of stable ground temperature*

Ground temperature is normally more stable than air temperature. It can therefore be used as a heat source in the winter, a source for cooling in the summer, as well as a location for storing food, thus reducing refrigeration energy. The supplied air through underground air ducts for preheating the air during the winter or cooling it during the summer, is however the most relevant measure.
**Potential:** Utilisation of terrestrial heat to stabilise supplied air is most relevant in residential buildings, due to low airflow and relatively more surfaces for heat exchange.
**Interaction:** Conflicts may arise with *2-7-1 Building with very low pollution level* as a result of reduced accessibility for cleaning of ducts for incoming air, though measures can be implemented to prevent this.

Measures to prevent condensation and mould risk associated with summer cooling in subsoil ducts are especially important.
**Documentation:** The effect is well documented in for example (Aschehoug, 2009) but is not included in conventional energy calculations. Calculations by hand or through simulation are possible.
**Priority:** 1 for residential buildings, 3 for commercial buildings.

### *1-2-9 Utilisation of air humidity*

Humidity from the environment can be used for cooling. The effect will however be marginal under normal circumstances where the outdoor night temperature is lower than the inside temperature, due to the fact that incoming air will quickly heat up which will reduce its relative humidity.
The effect can be achieved by pre- or simultaneous cooling of internal surfaces, culverts for supplied air, or the ceiling near the inlet.
**Potential:** Can probably be utilised in schools, etc., but results are uncertain.
**Interaction:** Must be coordinated with *3-1-2 Temperature buffering materials* and *3-2-1 Moisture buffering materials.*
**Documentation:** Inadequate documentation. Not included in any calculation programs**.**
**Priority:** 3 for both building categories

### *1-2-10 Utilisation of differences in gas pressure*

Gas will always flow from an area of high partial pressure to an area of low partial pressure. The greater the pressure difference is, the faster the gas stream flows. Water vapour, carbon dioxide and various organic gases can be transported to the outside through the buildings envelope, while oxygen will simultaneously travel in the opposite direction. The extent of the transport depends on the building envelope's diffusivity for relevant molecular sizes. The effect can be used to reduce the building's ventilation needs.
**Potential:** Reduced ventilation demands will lead to energy savings for all building types.
**Interaction:** Probably no direct conflicts, nor with *2-2-1 Sealing of external surface* as this measure is normally carried out even with materials with high diffusivity. Increased condensation risk of the exterior wall as a result of diffusion can be prevented by using materials with high moisture capacity, such as wood fibre.
**Documentation:** The effect is documented in (Simonson, 2000) and (Simonson, 2005). There is no calculation methodology currently available.
**Priority:** 3 for both building types as a result of inadequate documentation.

# Step 2 REDUCE

*Reduction of energy demand not handled by adaptation*

## 2-1 REDUCED CLIMATE SCREEN

### 2-1-1 Differentiated temperature levels

Differentiated temperature levels in buildings have positive health effects (Keith, 2006) and (Dear, 2011). Heating rooms beyond their needs can simultaneously be avoided. This includes reducing the operating temperatures in several parts of the building, as well as reducing the temperature of the area that is

heated. However this requires that the heating and ventilation system allows for differentiated temperature levels.
**Potential**: Larger spaces in many commercial buildings could be operated at a lower temperature levels. Nevertheless, the potential is likely to be greatest for residential buildings where the temperature levels could often be lowered in more than half the floor area. This presupposes that the use of multi-functional rooms with temperature discrepancies, e.g. bedrooms with workspaces, is avoided.
**Interaction:** The effect will be enhanced by coordination with *1-1-1 Co-localisation of rooms with equal temperatures*, *2-3-1 Thermal insulation of internal walls* and *2-3-2 Air tightening of internal walls.* It must also be seen in relation to *1-1-3 Utilisation of latent energy from water vapour* which could contribute to both heating as well as cooling.
**Documentation:** Can be calculated through simulation. The calculation methodology will however be in conflict with NS 3031 when it comes to residential buildings, as they are considered as having one zone. Other building types are calculated with adiabatic zones, in which actual heat or mass transfer are not included.
**Priority:** The measure is considered as readily usable and effective for residential and commercial buildings, and is therefore given priority 1 for both.

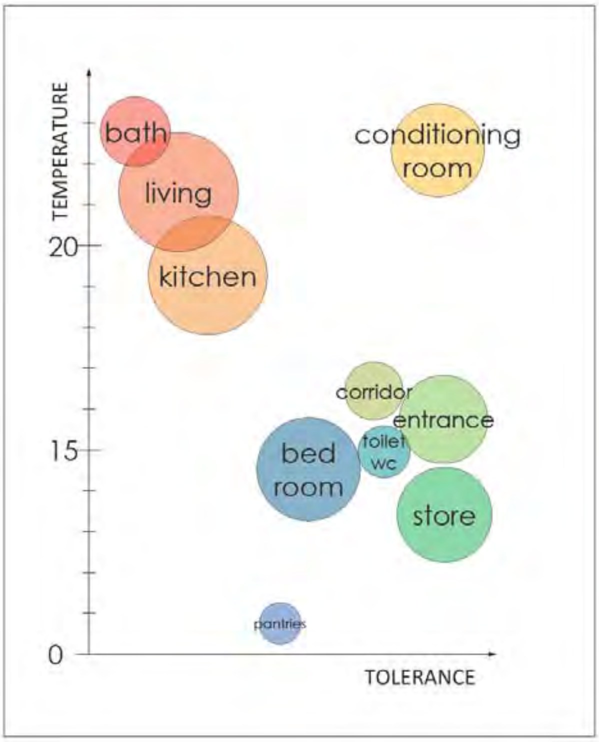


*Figure 11: Sketch of the different residential functions with their corresponding temperature levels. For the "Climate-room" feature, see Appendix 3.*

## 2-1-2 Reduced external surface area

Reduced external surface area will reduce transmission heat loss and infiltration. The magnitude of the effect depends on the temperature level, and will therefore be greatest for heated rooms. Minimum surface area is achieved with compact plans. Excessive protrusions, corners recessed balconies and entrances should be avoided.
**Potential:** The effect of reduced external surface area for heated rooms is significant for all building types.

**Interaction**: Will usually be enhanced with integration of the measure *2-1-1 Differentiated temperature levels* and *2-1-3 Unheated rooms position to external walls*. Conflicts can occur with demand for daylight, and thus lead to increased use of artificial lighting. There may be conflicts with measures *3-1-1 Temperature buffering room design* and *3-3-1 Pollution buffering room* design as these usually involve increased headroom.
**Documentation:** Is included in NS3031.
**Priority:** 1 for both residential and commercial buildings, but with a reservation if it conflicts with more effective measures.

### 2-1-3 Unheated rooms position to external walls

Heat loss from heated rooms to the external climate may be reduced by locating unheated or colder rooms adjacent to the building's exterior perimeter. This reduces the overall transmission heat loss. Infiltration and wind loads can also be reduced by locating these rooms against prevailing wind and rain directions for the location. This plan design allows unheated rooms to be partly heated by their adjacent heated rooms through transmission.
**Potential:** Will likely provide a significant energy reduction, especially in localities with harsh weather conditions.
**Interaction:** May conflict with demand for daylight or other functional criteria. Should be considered together with *1-2-2 Reduction of wind and air streams.* The effect will be enhanced by coordinating with *1.1.1 Co-localisation of rooms with equal temperatures* and *2.3.1 Thermal insulation of internal walls*.
**Documentation:** There are several relevant calculation programs available. The calculation methodology will be in conflict with NS 3031 which considers residential buildings as having only one zone.
**Priority:** 1 for both residential and commercial buildings. It is however probably most applicable in residential buildings because of the greater share of rooms with different temperature requirements.

## 2-2 IMPROVED CLIMATE SCREEN

### 2-2-1 Sealing of external surface

Air leakage through the building envelope accounts for a significant portion of the heat loss from a building, as an unintentional supply of cold air must be heated. Air leaks also reduce the building's insulation capability under increased wind loads.
**Potential**: The potential is significant, especially in buildings with mechanical ventilation using heat recovery, as a significant portion of the air change will happen without the heat recovery if the air sealing is poor. Nevertheless, increased air tightness will reduce the wind loads and moisture loads on the insulation layer regardless of the ventilation system.
**Interaction:** No conflicts. Though the effect of the air tightness will be reduced somewhat due to: *1-2-2 Reduction of wind and air streams, 2-1-3 Unheated rooms position to external walls,* and *2-3-2 Air tightening of internal walls.*
**Documentation:** Included in NS 3031
**Priority:** 1 for both building categories.

### 2-2-2 Thermal insulation of the building envelope

Insulation materials reduce the heat transfer through the construction and consequently the heating demand. The measure also includes prevention of thermal bridges in the construction, windows and doors.
**Potential**: Significant for all building types

**Interaction:** The degree of insulation should relate to a room's function and temperature requirement to prevent excessive insulation that might conflict with functionality of the room or unnecessary cost. The effect of the measure may be reduced by implementation of measure *1-2-6 Reduction of temperature differences.*
**Documentation:** Is included in NS 3031
**Priority:** 1 for both building categories.

### 2-2-3 Heavy and/or hygroscopic materials as thermal buffer

Using heavy and/or hygroscopic insulation materials will delay heat transfer through the building's envelope. The measure will have the greatest impact in the summer, and can be used with a customized selection of materials to delay midday heat from affecting the internal environment after the user period. The heat can then easily be ventilated.
**Potential:** Most applicable in commercial buildings where the cooling demand can be reduced, the effect will however be limited by excessively large window facades. Can also be relevant for residential buildings due to expected climate change.
**Interaction:** No conflicts, but must be considered together with *3-1-2 Temperature buffering materials.*
**Documentation:** Not included in conventional energy calculation. There is currently limited documentation on this measure, see (Lawrence, 2012), (CIBSE, 2006) and (Nordby, 2013).
**Priority:** The measure is considered as interesting, but is given priority 2 for both commercial and residential buildings due to inadequate documentation.

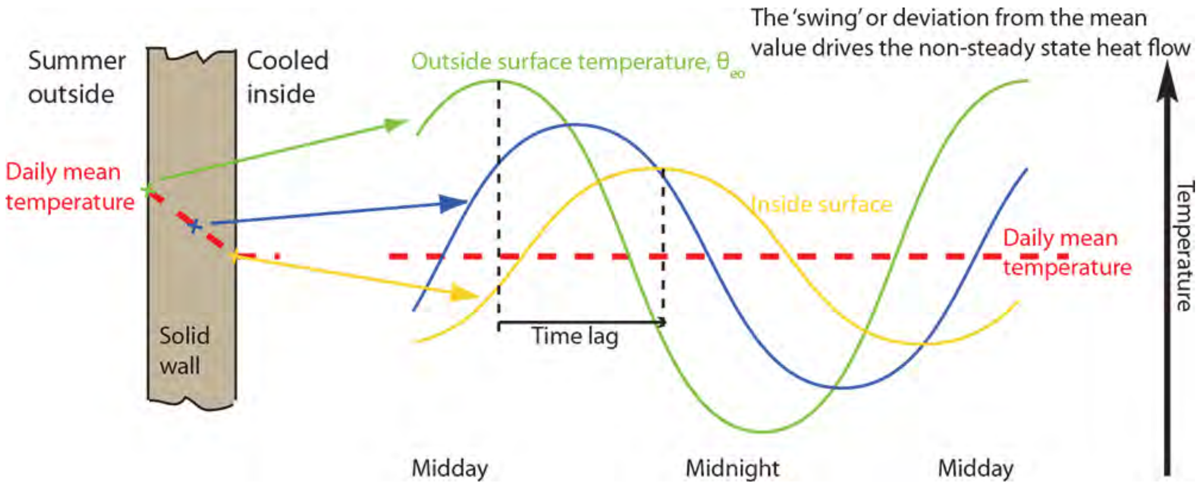


*Figure 12: Principle of thermal buffering (CIBSE, 2006)*

## 2-3 IMPROVED INTERNAL PARTITIONS

### 2-3-1 Thermal insulation of internal walls

The heat transfer between rooms with different temperatures can be reduced by thermally insulating the internal partitions. A stable room temperature will then be easier to obtain without the need for heating or cooling. But in some cases heat transfer is desirable, such as from heated to unheated rooms. This

diminishes the need for unheated rooms to have an own heating source. The degree of transfer can be adjusted through the use of materials and insulation thickness.
**Potential:** Probably significant for residential buildings that have implemented *2-1-1 Differentiated temperature levels.* Will probably also have positive effects in commercial buildings.
**Interaction:** The effect will be enhanced through cooperation with *1-1-1 Co-localisation of rooms with equal temperatures.*
**Documentation:** Is calculated adiabatically through simulation in e.g. IDA-ICE. Calculation methodology will however be in conflict with NS 3031 when it comes to residential buildings, as they are calculated as having one zone.
**Priority:** 1 for both building categories.

### 2-3-2 Air tightening of internal walls

Infiltration through internal partitions will occur due to pressure differences. Unwanted heat transfer will therefore occur if the rooms have different temperatures. The effect can be particularly significant for rooms adjacent to rooms with window ventilation. Internal sealing may reduce the heat transfer. An important aspect here is to reduce the use of doors between affected rooms, or possibly equip them with sealing strips.
**Potential:** The effect will primarily be related to indoor comfort and prevention of draught, but it is also reasonable to assume that the measure may affect the heating requirements.
**Interaction:** No conflicts, but must be viewed together with measures *2-3-1 Thermal insulation of internal walls.* The effect will also be enhanced through measure: *1-1-1 Co-localisation of rooms with equal temperatures.*
**Documentation:** Insufficient documentation, but the effect can probably be simulated.
**Priority**: 1 for residential and 2 for commercial buildings.

## 2-4 REDUCED TEMPERATURE LOAD

### 2-4-1 Reduced internal surplus heat

The extent of internal excess heat from activities and equipment can be reduced, for example by lowering the demand for artificial lightning, increasing insulation and reducing the length of hot water pipes, and a consistent prioritisation of equipment with the lowest possible heat loss, i.e. highest energy efficiency rating. The energy savings will mainly be noticed from reduced cooling demand in the summer, as well as in rooms with cooling requirements throughout the year, such as food storage.
**Potential:** Probably little to gain in residential buildings as a large part of the surplus heat can be utilised, see *1-1-2 Utilisation of internal surplus heat*. Commercial buildings have a larger potential, particularly in relation to technical rooms, hot water pipes, print rooms etc.
**Interaction:** Must be considered together with measures *1-1-2 Utilisation of internal surplus heat*. The effect will decrease as measure 1-1-2 is increased.
**Documentation:** Standard values for internal loads are specified in NS 3031. However it is uncertain whether the potential in 2-4-1 is large enough to challenge these values. The effect can be calculated by hand.
**Priority:** 3 for both residential and commercial buildings.

# 2-5 REDUCED TEMPERATURE LEVEL

## 2-5-1 Surfaces with low thermal conductivity

Radiation exchange with surrounding surfaces can account for a significant proportion of heat loss from a human body. Surfaces that quickly dissipate heat will have a slightly lower surface temperature and thus also less reflected radiation. Therefore, a good comfort temperature can be maintained at a low air temperature by using surface materials with low thermal conductivity.
**Potential:** Very small reductions in air temperature can result in significant energy savings. This will apply to all building types.
**Interaction:** Must be seen in conjunction with measures *3-1-2 Temperature buffering materials,* it will also interact with measure *1-1-3 Utilisation of latent energy from water vapour* and *3-2-1 Moisture buffering materials* as increased moisture content will enhance a material's thermal conductivity.
**Documentation:** The measure is inadequately documented.
**Priority:** Unresolved

## 2-5-2 Improved user control

Humans have a higher tolerance for temperature changes in buildings with user-controlled natural ventilation. One reason for this is the faster response time and more accessible adjustment options available, such as in window ventilation.
**Potential**: Significant for all building types, especially buildings in which the users are engaged in more sedentary activities.
**Interaction:** Will interact well with a variety of other measures, including *1-1-2 Utilisation of internal surplus heat* and *1-2-5 Utilisation of solar radiation,* as higher operating temperatures will be accepted. It does not conflict with other measures, but it requires a natural ventilation system with straightforward and effective method of regulation.
**Documentation:** Well documented, (Dear, 1998), and accepted within current design criteria for energy performance of buildings, (EN 15251), but it presuppose that relevant rooms should have adjustable windows and ventilation systems that can easily be operated by the users.
**Priority:** 1 for both residential and commercial buildings.

# 2-6 REDUCED HUMIDITY LEVEL

## 2-6-1 Reduced moisture production

The ventilation needs associated with increased relative humidity will be reduced by lowering the moisture production internally.
**Potential:** The possibilities for reducing moisture production are small in most buildings. Exceptions are rooms where plants are watered, rooms with swimming pools and similar special-purpose buildings. There may also be conceivable technical solutions that could reduce the moisture emission from cooking.
**Interaction:** Must be considered together with *1-1-3 Utilisation of latent energy from water vapour* which can maintain the energy content of supplied moisture on the condition that it is intermittent. The effect of this measure will be greatly reduced or eliminated by utilising *3-2-1 Moisture buffering materials.*
**Documentation:** The benefits on indoor air quality of reducing the moisture load are well documented. There are however no guidelines to calculate the energy effect from reduced moisture load. But it can be calculated by hand.
**Priority:** 3 for both building categories as the effect is considered inadequately investigated.

# 2-7 REDUCING POLLUTION LEVEL

## 2-7-1 Building with very low pollution levels

The ventilation demand could be reduced by reducing the internal pollution load from building materials, furnishings and processes.

**Potential:** Is considered significant in all building types, especially in relation to reduced ventilation during the winter and outside periods of use.

**Interaction:** There are probably no conflicts, but the effect will be reduced by implementing measures *2-7-2 Materials with nanoparticles for photo catalytic degradation of pollutants*, *2-7-3 Air purification through plants* and *2-7-4 Materials that binds air contaminants.*

**Documentation:** It is well documented, and is defined in NS-EN 15251. To date it is only credited for commercial buildings.

**Priority:** 1 for commercial buildings and priority 2 for residential buildings.

## 2-7-2 Photo catalytic degradation of pollutants

Exposed materials of plasterboard, cement products, etc. which are given nanoparticles of titanium dioxide, will be able to break down various gas pollutants in indoor air by so-called photo catalytic oxidation (PCO) into primarily water vapour and carbon dioxide.

**Potential:** It can have an effect in all types of building. The measure is however costly, as well as the life expectancy and results of the degradation are unpredictable.

**Interaction:** Will reduce the effect of *2-7-1 Building with very low pollution level*. The effect will also depend on the moisture situation and must therefore be considered along with *3-2-1 Moisture buffering materials.*

**Documentation:** The measure is not included in conventional calculation. There is considerable documentation, such as (Chuck, 2013) and (Petersson, 2009), but the measure is still insufficiently investigated. There are some environmental doubts.

**Priority:** 3 for both building categories.

## 2-7-3 Air purification by plants

Plants or bio filters have the ability to break down some pollutants to CO2 and water.
Biodegradation processes are primarily based on microorganisms attached to the roots of the plants and the cultivation medium they are grown in. Plants also bind particulate contaminants, predominantly through the leaf.

**Potential:** Is in principle relevant for all building types.

**Interaction.** Plants can also be used for humidification, as seen in (and must be considered with) *1-1-3 Utilisation of latent energy from water vapour.*

**Documentation.** The effect of the measure must be considered inadequately investigated at present, although some documentation is available, such as (Kim, 2008). There are also surveys that show positive user response in premises that contain living plants. However it is claimed that this might also be caused by psychological effects, see (Bringslimark, 2007). No calculation models were available for this report.

**Priority:** 3 for both building categories as a result of inadequate documentation.

### 2-7-4 Materials that bind air contaminants

Exposed materials of plaster or cement that are given activated carbon, silica gel, zeolite or pure wool can absorb and bind air pollutants permanently. The absorption will continue until saturation. The materials must then be replaced.

**Potential:** The measure could be relevant in all building types, especially for periods of increased pollution loads, such as during the drying out process for new buildings. Possibly with the exception of light wool, the constant renewal of materials would be costly.

**Interaction:** The measure must be seen in relation to *2-7-1 Building with very low pollution level.*

**Documentation:** Must currently be considered as immature and inadequately investigated

**Priority:** 3 for both building categories.

# Step 3 STABILISE

*Optimizing and predisposing the remaining energy flows in relation to the use cycles and local climate cycles.*

## 3-1 TEMPERATURE STABILIZATION

### 3-1-1 Temperature buffering room design

Room volume above head height can be used as a buffer to prevent overheating. The measure will have a short reaction time, and the greatest effect in rooms with displacement ventilation and sedentary activities. It is assumed that the buffer volume is flushed regularly.

**Potential:** Will reduce cooling and ventilation demands in schools and offices, and in general all buildings that need quick response to heat loads from solar radiation or people. The measure is also applicable in residential buildings.

**Interaction:** Could conflict with *2-1-2 Reduced external surface area*. Should be considered in relation to *3-3-1 Pollution buffering room design*. Can in some extend be replaced with *3-1-2 Temperature buffering materials*, when involving solutions related to latently heat storage (LHS).

**Documentation:** The measure is not included in conventional calculations for ventilation demands. The effect is however well documented, such as in (Hamilton, 2004). The measure can be simulated and calculated in IDA-ICE.

**Priority**: 1 for commercial buildings and priority 2 for residential buildings.

### 3-1-2 Temperature buffering materials

Temperature buffering materials in the building interior will reduce temperature variations, prevent overheating from incoming solar radiation and internal surplus heat, as well as contribute to better use of heat. The measure can also be used for natural night cooling. Conventional temperature buffering (Sensible Heat Storage SHS) is slow and is based on the material's thermal capacity and thermal diffusivity. Rapid buffering can be performed with phase change materials (PCMs, latent Heat Storage, LHS) as well as hygrothermal mass where the humidity is utilized through condensation and evaporation in hygroscopic claddings.

**Potential:** It is estimated that effective temperature buffering can reduce energy consumption for heating by 6 to 20% depending on the type of building (Kram, 2001). The effect on the cooling demand can be even greater, especially in commercial buildings where over 30% reduction has been documented (Dokka,

2005). Energy reductions of up to 50% have been calculated for school buildings, suggesting that the excess heat from the students can be better utilised (Hagentoft, 1997). The relevance of the measure will increase with future climate change.
**Interaction**: Should be coordinated with measures *1-1-3 Utilisation of latent energy from water vapour*, *1-2-5 Utilisation of solar radiation, 3.1.1 Temperature buffering room design* and *3-2-1 Moisture buffering materials*.
**Documentation:** The effect of conventional temperature buffering (SHS) is relatively well documented and is included in current computational models, such as NS 3031. More detailed calculations can be made in IDA-ICE. The effect of LHS and the use of hygrothermal buffers are currently inadequately documented but can be calculated in IDA-ICE.
**Priority:** 1 for both residential and commercial buildings.

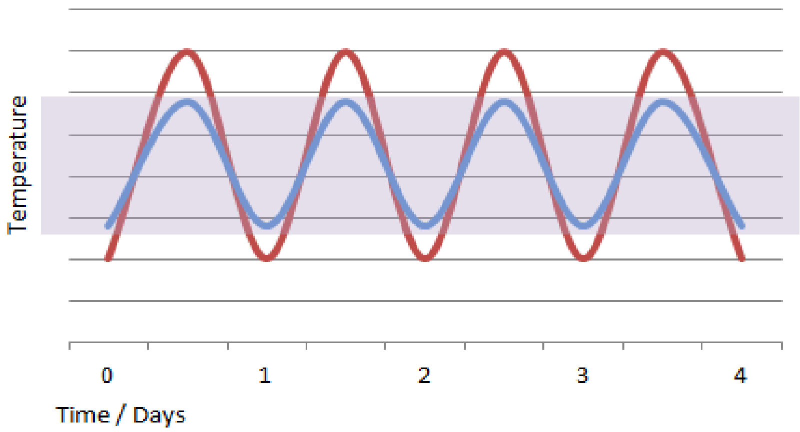


*Figure 13: Principle of stabilizing room temperature with materials*

*See Appendix 3 for example with use of wood*

## 3-2 STABILIZATION OF MOISTURE

### 3-2-1 Moisture buffering materials

Hygroscopic materials in the building interior stabilize the relative humidity (RH) by taking up moisture when the RH in the room rises and return it again when the RH drops. Response time is usually faster than by conventional ventilation. It simultaneously prevents condensation on surfaces and behind furnishings, etc. Thus the ventilation demand relative to moisture will decrease, as well as problems related to dry indoor air. Moisture buffering will primarily provide an effect for 24-hour periods, but it is also applicable during longer cycles such as a week, during periods of low pressure and throughout the seasons. The buffers must be discharged regularly, either by constant ventilation or by forced ventilation.
The use of moisture buffering will also contribute to improve the perceived air quality (PAQ). Perceived air quality consists amongst other things, of air temperature and RH, which describes the total energy content of the air (enthalpy). Reducing the RH achieves the same improvement of the PAQ as reducing the air temperature. This means that in periods where there is a demand for cooling, a higher air

temperature can be tolerated, (Fang, 1998). This in turn means that cooling energy can be reduced quite significantly.

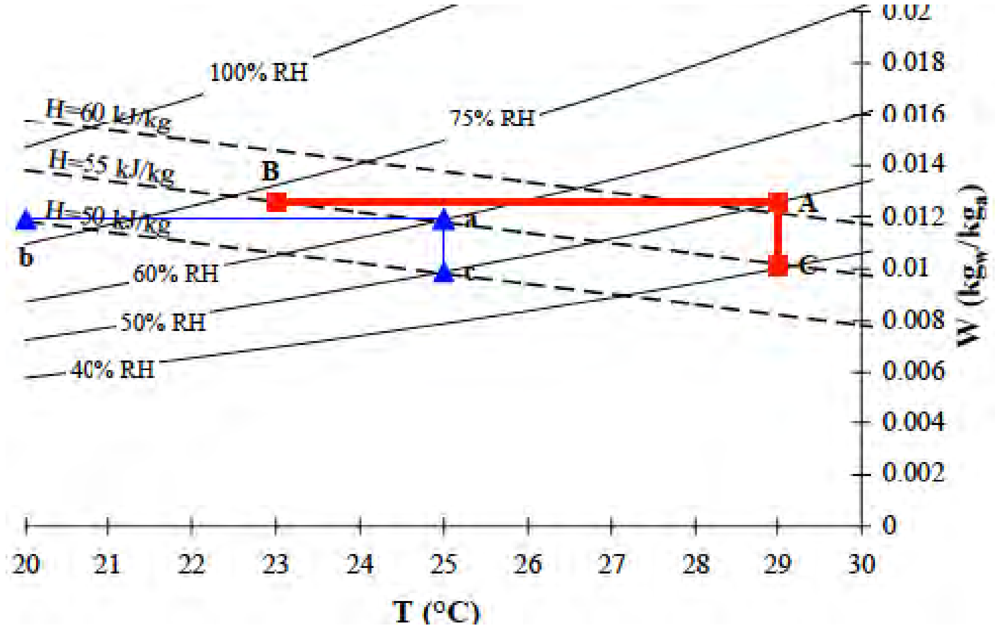


*Figure 14: The air will reduce its heat content by 5 kJ/kg by cooling the air from 29 degrees to 23 degrees without removing moisture (A-B). The same can be achieved by lowering the RH from 50% to 40% (A-C), (or 60% to 50% (a-c)). A-B is achieved by using ventilation or mechanical cooling, while A-C can be achieved through the use of hygroscopic cladding materials (Simonson, 2000).*

**Potential:** The measure is applicable in all types of buildings with periodic use and/or moisture loads. It is estimated that the ventilation demand in the winter will be reduced by 30-40% by using moisture regulating finishes in rooms that have a normal moisture load and moisture controlled ventilation (Woloszyn, 2009). The effect will be less in the summer, primarily because of the higher moisture content in the outdoor air.
**Interaction:** Moisture buffering will have an indirect influence on the room temperature, see *3-1-2 Temperature buffering materials* and *1-1-3 Utilisation of latent energy from water vapour.*
**Documentation:** The effect of moisture buffering is relatively well documented, such as in (Korsnes, 2012) and (Allinson, 2010). It is however not included in the current calculations for TEK. Some softwares that can be used to calculate the performance are: IDA-ICE, WUFIplus, BSIM and HAMT (which is an addition to British Energy Plus)
**Priority:** 1 for both residential and commercial buildings.

*See examples in Appendix 3*

## 3-3 STABILIZATION OF AIR CONTAMINANTS

### 3-3-1 Pollution buffering room design

Room volume above head height can buffer light pollution loads and pollution with higher temperature such as exhaust gases from exhalation, cooking, office machines, etc. The measure will have short

reaction time, and will have greatest effect in rooms with displacement ventilation and sedentary activities. It is assumed that the buffer volume is flushed regularly.
**Potential:** Could reduce ventilation requirements, particularly in schools, community halls and perhaps office rooms with extensive technical equipment. For residential buildings the measure will foremost contribute in the bedrooms.
**Interaction:** Could conflict with measures *2-1-2 Reduced external surface area* and interact directly with *3-1-1 Temperature buffering room design*
**Documentation:** The effect is well documented. See studies such as (Hamilton, 2004). It is not included in current calculation methods for ventilation requirements. Can be calculated by using IDA-ICE.
**Priority**: 1 in commercial buildings and priority 2 for residential buildings.

### 3-3-2 Pollution buffering materials

Many porous materials will have the ability to stabilize the pollution level in the indoor environment by absorbing gases when the concentration increases and returning them when the concentration decreases. The speed of the process diminishes as it nears equilibrium. Molecular size and chemical reactivity between gas and material can expedite or delay the process and possibly increase or reduce the capacity. The buffers must be emptied regularly outside the user period.
**Potential:** The measure might reduce ventilation requirements, but primarily in relation to contamination from people and activities in buildings with periodic use. The potential will be marginal for continuous contamination from materials etc., and should then be combined with intensified ventilation a few hours before the period of use.
**Interaction:** Should be seen in conjunction with *3-2-1 Moisture buffering materials*, since the measure uses similar materials. The contaminants may also follow the migration of moisture as it enters and exits a wall.
**Documentation:** The documentation is currently inadequate, but is under development. See studies including (Sherman, 2013), (Hansson, 2003) and (Jørgensen, 2007). The effect of the measure could probably be calculated by hand.
**Priority**: 2 for both building categories due to insufficient documentation.

# Appendix 2 Building simulation, complementary

## Objective

It is assumed that buildings designed according to the principles of the Norwegian passivhaus standard NS 3700 will have a major impact on the energy consumption for heating and ventilation.

The primary goal of the simulations is to examine whether the same energy efficiency can be achieved by buildings designed and operated by the principles of the *LIMA Pyramid*.

Specific purposes of the calculations are:

- To calculate the energy consumption for heating and ventilation for a residential building designed by the principles of the *LIMA Pyramid*, absolute passive design with natural ventilation.
- To investigate whether passivhaus level is achievable in buildings designed by the *LIMA Pyramid*.
- To investigate the preconditions for achieving passivhaus level in buildings designed by the *LIMA Pyramid*.
- To compare the energy consumption for a similar building designed on conventional principles using mechanical ventilation with heat recovery. The reference building has however some extra passive design measures that extend beyond requirements seen in NS 3700.

## Method

Simulations are done in IDA ICE - version 4.6.1 (EQUA, 2014).
The prerequisites in EN 15251 are followed apart from the bedroom temperatures. Deviations from NS3031 are commented.

The simulated building has 115 m² heated gross internal area, and is designed on the principles in the *LIMA Pyramid*. The model is a two stories residential building as shown in *Figure 15*. The same model is used for energy calculation using natural ventilation (*Absolute passive model APM*) and mechanical ventilation (*Mechanical model MEC*). The model consists of 22 zones, 12 zones in the heated zone and 10 zones outside.

To simulate user-controlled ventilation, indicators for $CO_2$ levels, temperature and RH are used as indicators of presence and activity, which then indicate the need for ventilation in the different rooms.

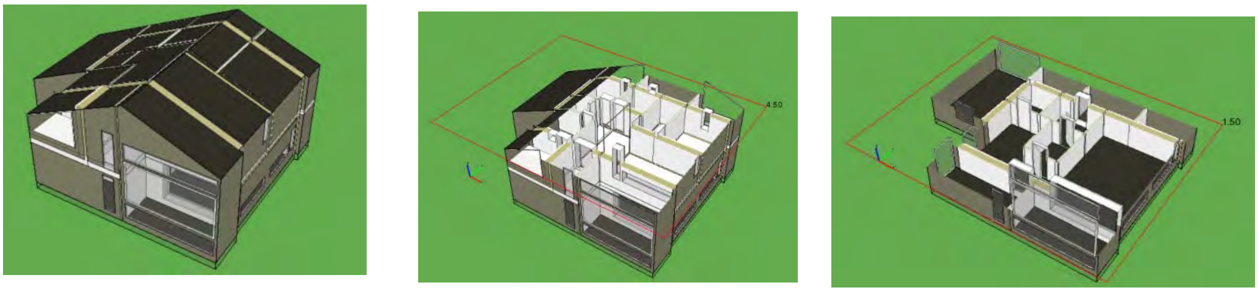

*Figure 15: Residential building*

The difference between the two physical models is mainly the ventilation principle:

- *Absolute passive model (APM)* has natural ventilation and a conditioning room (an unheated glazed room which uses the sun to preheat the incoming air) facing south. *Mechanical model (MEC)* has mechanical ventilation and no conditioning rooms. The principle of conditioning room is further explained in appendix 3.
- *Absolute passive model (APM)* has demand controlled natural ventilation (controlled by CO2 and temperature in the living rooms, and RH in bathrooms). *Mechanical model (MEC)* has balanced ventilation with constant supply and exhaust air.
- *Absolute passive model (APM*) has gas tight bedroom doors. *Mechanical model (MEC)* has doors with exhaust vents to adjacent rooms.
- *Absolute passive model (APM)* has 100% window airing of the bedrooms at night (26 m³/h/pers.). *Mechanical model (MEC)* has a mainly mechanical ventilation with overflow to hallway, living room, bath (20 m³/h/pers.) supplemented with 23% windowed aeration (6 m³/h/pers.).

Ventilation principles in the *Absolute passive model* are shown in *Figure 16* and the *Mechanical model*, in *Figure 17*.

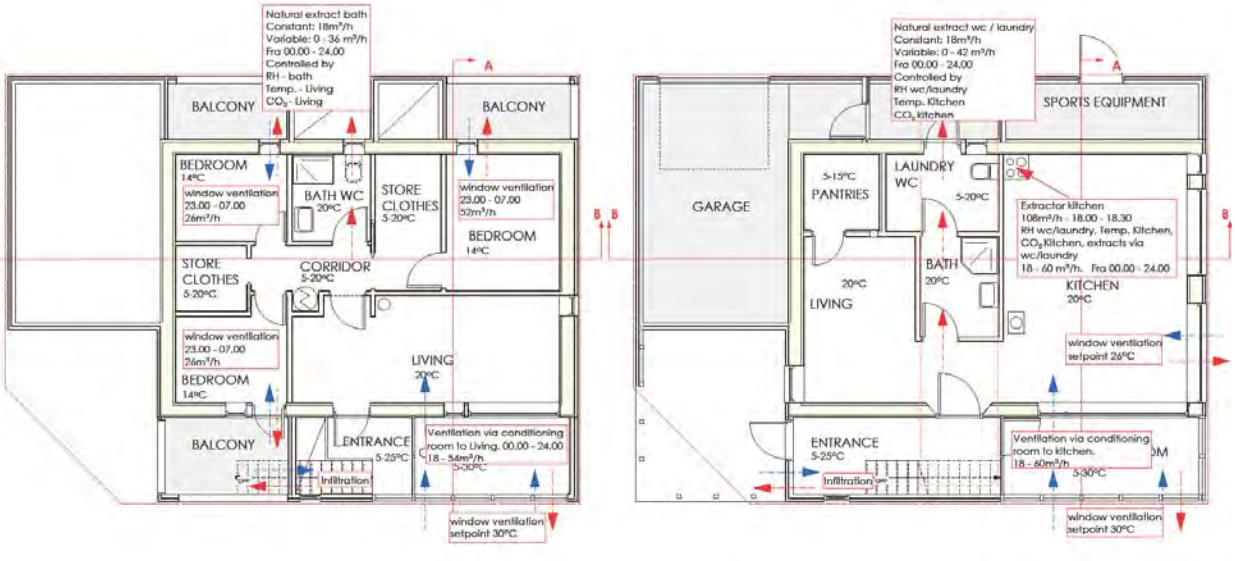


*Figure 16: Ventilation Principle of Absolute passive model (APM). Ground floor to the right. (Text will emerge by electronic magnification.)*

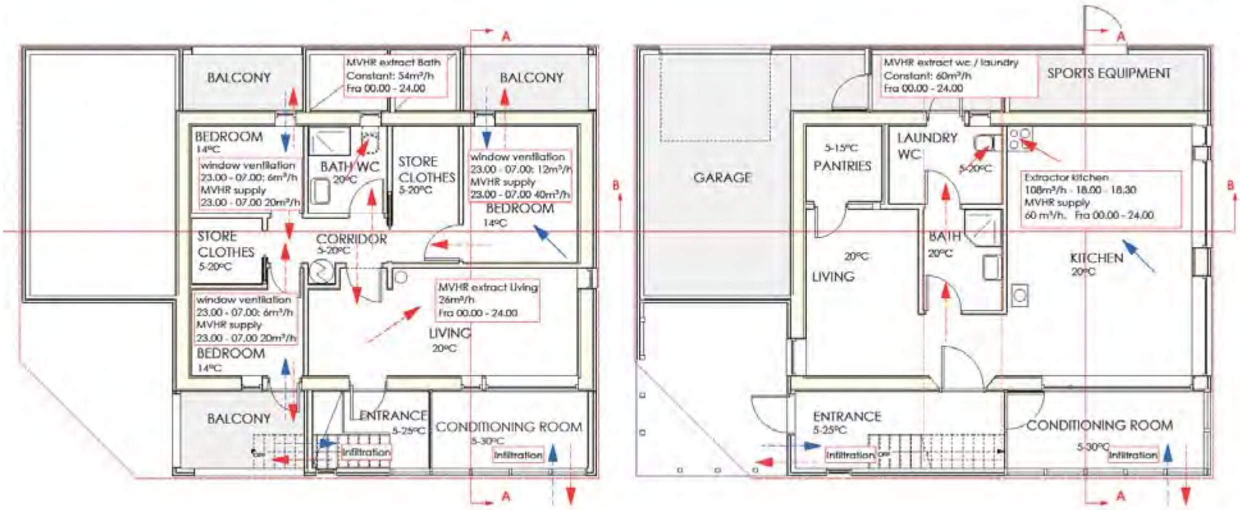


*Figure 17: Ventilation Principle in Mechanical model (MEC). Ground floor to the right. (Text will emerge by electronic magnification.)*

The following calculations were made on the basic model, but with varied conditions:

| | |
|---|---|
| APM 0 - APM 3 | - are simulated for Oslo climate (Humid continental climate) |
| APM 4 | - is simulated for Bergen climate (Maritime climate) |
| | |
| MEC 0 - MEC 1 | - are simulated for Oslo Climate (Humid continental climate) |
| MEC 2 | - is simulated for Bergen Climate (Maritime climate) |

## APM 0 - Passive reference

APM 0 is a reference model and uses current TEK10 and NS3031 as the basis for the calculations in the simulation.
Deviations are:

- The heat and moisture load from inhabitants conforms to the user profile of presence and is not evenly distributed as assumed in the calculation methodology for NS 3031, this deviation is necessary to place the moisture loads at the correct time of the day.
- The calculation takes into account the moisture loads from kitchen and shower.
- 

## MEC 0 - Mechanical reference

MEC 0 is a reference model and uses current TEK10 and NS3031 as the basis for the calculations in the simulation
Deviations are:

- The heat and moisture load from inhabitants conforms to the user profile of presence and is not evenly distributed as assumed in the calculation methodology for NS 3031
- The calculation takes into account the moisture loads from kitchen and shower.

### APM 1 - Passive design with demand controlled natural ventilation

Calculation based on model APM 0, but with the following changes:

- Natural ventilation: It is ventilated with a constant base ventilation of 2x18 $m^3$/h on the ground floor and on the 1st floor. The base ventilation is supplemented with demand-controlled ventilation. The supplementary ventilation on the ground floor is simulated by indication of presence in the living room and kitchen, indicated by $CO_2$ and temperature, as well as RH in the WC. The supplementary ventilation on the 1st floor is initiated by presence from work and play, which is indicated by $CO_2$ and temperature, and RH in bathrooms.

### APM 2 – Buffer room

The model is equivalent to APM 1, but is supplemented with a buffer room on the south facade. The incoming air is brought into the buffer room where it is preheated before entering the heated zone.

### APM 3 - Adaptive model with thermal zones

The model is equivalent to APM 2, but uses different temperatures for different zones of the building:

- Porch: temperature changed from 21/19ºC to a fluctuating temperature above 5ºC.
- Bedroom: temperature changed from 21 /19ºC to a fluctuating temperature above 14ºC.
- Food storage, clothing rooms, and other rooms for storage are not heated.
- Bathroom: temperature changed from 21/19ºC to a constant temperature of 20ºC as a result of the use of latent heat.
- Remaining room temperature changed from 21/19ºC to constant 20/19ºC due to the use of latent heat.

### APM 4 - Bergen Climate

The model is equivalent to APM 3, but the calculations apply the Bergen climate instead.

### MEC 1 - Thermal Zoning

The model is equivalent to MEC 0, but different temperatures are used for different zones of the building:

- Porch: temperature changed from 21/19ºC to a fluctuating temperature above 5ºC.
- Bedroom: temperature changed from 21/19ºC to a fluctuating temperature above 14ºC.
- Food storage, clothing rooms, and other rooms for storage are not heated.

### MEC 2 - Bergen Climate

The model is equivalent to MEC 1, but calculations are done with the Bergen climate instead.

## Limitations of the simulation

A full simulation of the moisture dynamics for internal wood surfaces were difficult to implement in the available version of IDA-ICE, though the main effects from moist regulation in relation to ventilation requirements and temperature equalisation are included.

## Summary and results from the residential building simulation

Calculation results are summarised in table 4 (below). These show that:

- The simple model for passive design, APM 0 (with NS3031 as the basis for the calculation), does not meet the requirement for energy efficiency.

- Presence controlled regulation (moisture, $CO_2$ and temperature) of natural ventilation reduces the calculated energy consumption significantly. NS3031 doesn't allow this to be used for energy calculation, so it will require a deviation from NS3031. The measure requires a system that efficiently regulates the volume of the extracted air in the natural ventilation system. This can be automated, or performed manually by adapted design. The increased tolerance for temperature mentioned in *2-5-2* may be expected, but it has very little significance on the energy consumption.
- Preheating the incoming air in the buffer room is an effective strategy to reduce the energy use for heating.
- Passivhaus levels can be reached in both Bergen and Oslo climate for a passive building following the LIMA pyramid principles. This requires that the design facilitates for a widespread use of thermal zoning, and that this should be used in the energy calculations.
- A model with mechanical ventilation (MEC) will with the same preconditions have a generally lower energy use for heating compared with absolutely passive model APM. The two alternatives with thermal zoning will have similar energy use if the energy used for fan operation is included.

*Table 4: Result overview of energy used for heating and fans. Blue rows for Oslo Climate and yellow for Bergen Climate.*

| Models | Net energy use heating [kWh/m²/year] | Net energy use fans [kWh/m²/year] | Total net energy use [kWh/m²/year] |
|---|---|---|---|
| *References* | | | |
| Passivhaus level after NS3700, Oslo climate | 22,9 1) | 4,5 2) | 27,4 |
| Passivhaus level after NS3700, Bergen climate | 22,3 3) | 4,5 | 26,8 |
| Passivhaus level – TEK2015 (Smits, 2013) alt. A (net energy) | 30,0 4) | 4,5 | 34,5 |
| APM 0 Reference passive design - NATVENT | 53.0 | 0.6 7) | 53.6 |
| MEC 0 Reference active design - MECVENT | 23.9 | 4.3 | 28.2 |
| **Variations passive model:** | | | |
| Oslo climate: | | | |
| APM 1 Demand control VENT (indicator $CO_2$/temp./RH) | 35.4 | 0.6 | 36.0 |
| APM 2 AP1 + conditioning room | 31.2 | 0.6 | 31.8 |
| APM 3 AP2 + thermal zone | 20.3 5) | 0.6 | 20.9 |
| Bergen climate: | | | |
| APM 4 AP2 + thermal zones | 16.1 6) | 0.6 | 16.8 |
| **Variations mechanical model:** | | | |
| MEC 1 Reference + thermal zones, Oslo climate | 16.2 | 4.3 | 20.5 |
| MEC 2 Reference + thermal zones, Bergen climate | 12.6 | 4.3 | 16.9 |

**Notes:**
1) Residential building with 115m² GIA; Oslo Climate. Annual mean temp. 6.1°C, (Kvande, 2012)
2) No requirements; Normal energy use estimated; Includes demand-controlled exhaust in the kitchen.
3) Residential building with 115m² GIA. Bergen Climate. Annual mean temp. ≥ 6.3°C, (Kvande, 2012)
4) Estimation based on total net energy consumption of 95 kWh/m² per year
5) Corresponds to: "Absolutely passive energy design, Oslo climate" in *Table 3*, Chapter 2
6) Corresponds to "Absolutely passive energy design, Bergen climate" in *Table 3*, Chapter 2
7) Natural ventilation with demand controlled exhaust in the kitchen

# Appendix 3 Wood as a passive energy measure

Wood has climatic properties such as absorbing and releasing moisture, due to the porous structure of the material. Wood has a larger capacity than many comparable materials.

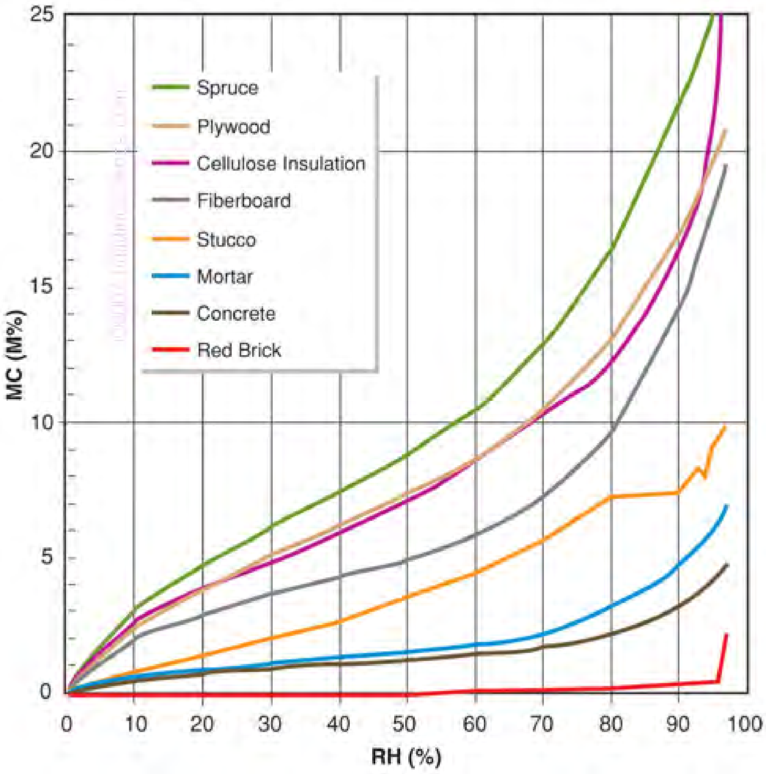


*Figure 18: Sorption (including both absorption and adsorption) curves for a variety of building materials, moisture capacity for different relative humidities (Straube, 2006)*

Wood will be of particularly interest in the following measures:

*1-1-3 Utilisation of latent energy from water vapour*
*3-1-2 Temperature buffering materials*
*3-2-1 Moisture buffering materials*

All measures require that the wood is untreated or that it has a vapour permeable surface, see *Appendix 4*.

## Further elaboration 1-1-3: Utilisation of latent energy from water vapour

The surface of wood will quickly absorb moisture until an equilibrium state is met when the relative humidity (RH) in the room rises. This process emits heat as the moisture goes from vapour to water. When the relative humidity decreases again, the process will reverse and cause a cooling of the environment. The process is essentially a zero-sum energy game but it could be used beneficially by adapting to user cycles, like heating of a bathroom.

Bathrooms are normally heated to approximately 3°C above the temperature of other habitable rooms to provide additional comfort. The higher bathroom temperature is in reality only necessary immediately after bathing during drying and dressing. A temperature increase of 2-5°C can be achieved after showering if the bathroom surfaces are finished in wood, due to the heat that is released from vapour absorbed by the surfaces. The bathroom does not need any additional heating system beyond the basic heating system of the house as the increased temperature can last for approximately a half an hour after absorption.

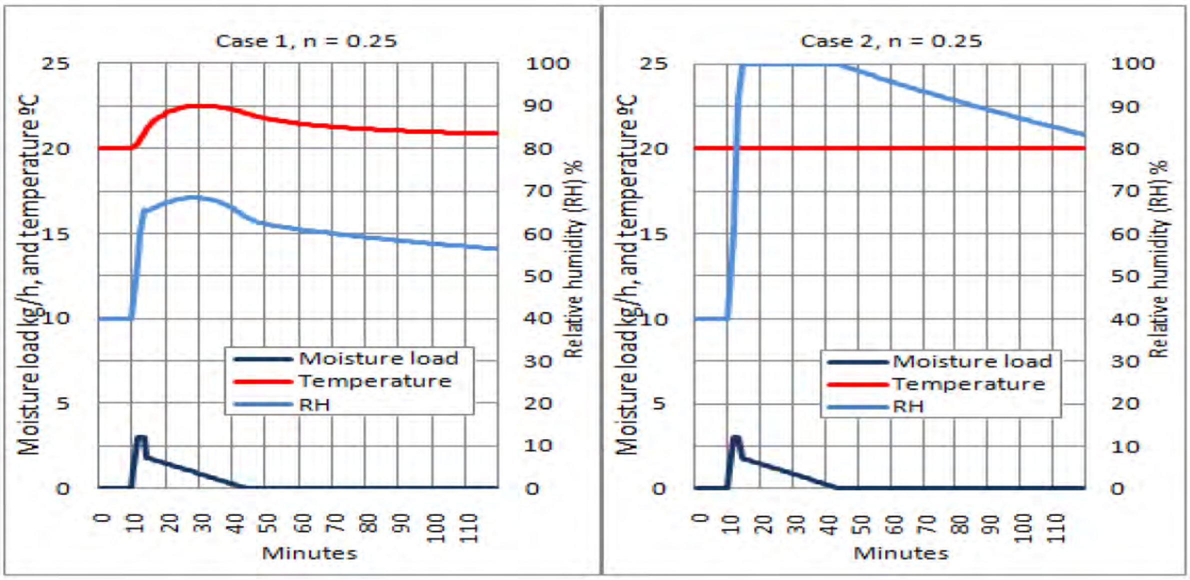


*Figure 19: The figure shows the changes in RH and temperature through a shower phase for two bathrooms where walls and ceilings are covered with wood panels (left) and non-hygroscopic surfaces (right). Calculated with WUFI Plus with 0.25 air changes per hour. Calculations for 0.5 and 1.0 air changes per hour produces the same pattern but has a slightly faster reduction of RH after the shower phase (Korsnes, 2012).*

The RH in the bathroom is usually between 40 and 55%, but increases up to 100% during showering if the steam is not efficiently removed by an exhaust fan. Most of the steam is absorbed by the wood and will therefore prevent condensation on smooth surfaces such as mirrors. The cumulative humidity is usually able to dry several hours before a new shower phase.

The energy effect of the measure was calculated with WUFI Plus by Nore and Olsson (Nore, 2014). The basis of the simulation was a bathroom of 12 m$^2$, with two showers daily. The results showed an energy saving of 296 kWh/year for Oslo Climate and 320 kWh/year for Tromsø Climate (northern part of Norway).

*Figure 20: Bathroom with wood surfaces (Photo: Sami Rintala)*

## Further elaboration 3-1-3: Temperature buffering materials

Wood has in principle a low heat capacity compared to heavier materials such as concrete and brick, however when it is combined with moisture it represents a hygrothermal mass with significant heat storage abilities. Only the outermost part of the wood will be moistened under normal conditions. The underlying part of the material will insulate and ensure that energy is mainly radiated back into the room, due to the fact that the material has relatively poor thermal conductivity.

The utilisation of hygrothermal mass is based on changes in the moisture balance which causes energy to be absorbed and then released. In practice it is often difficult to match the user cycles with the moisture cycles in a house, but it may be possible to achieve this in some situations.

Most relevant is the use of hygrothermal mass to capture and temporarily store solar energy in residential buildings. Wood will absorb moisture from humans and other processes during which evaporation takes place. When exposed to the sun the wood will dry out, making it ready to receive new moisture loads in the afternoon and evening. Moisture will condense in the wood surface, and thus increase the temperature. The efficiency and duration of the process will increase inversely with its ability to dry out.

There may be some uncertainties regarding the moisture load in the wood when the sunlight first hits it. A lot of the moisture produced during the night could have already been ventilated, and the access of moisture would then be limited to what has been produced during the morning hours, which may prove to be insufficient.

This situation might be remedied by equipping the building with a separate *conditioning room* that will supply the building with air. For a residential building this could be a south facing conservatory with large hygroscopic capacity where leafy plants throughout the day will continuously provide moisture as the temperature increases. This will bind large amounts of energy that can be used to heat the remaining rooms after sunset.

*Conditioning rooms* can also be used in commercial buildings. This would require removal of moisture during the night, which might be best accomplished using air ducts with high hygroscopic capacity.

## Further elaboration 3-2-1: Moisture buffering materials

Surfaces of wood will stabilize internal humidity by taking up moisture when RH rises and return it when RH again drops. This reduces ventilation demands linked to high moisture levels in the indoor environment and diminish the risk for mould formation behind furniture.

The use of moisture buffering will also contribute to improving the perceived air quality (PAQ). Perceived air quality is comprised of, among other things, air temperature and RH which describes the total energy content of the air (enthalpy). Reducing the RH achieves the same improvement of the PAQ as reducing the air temperature. (Fang, 1998)

The effect of hygroscopic surfaces in bedrooms, having the highest moisture loads in a dwelling, was examined by Simonson et al, (Simonson, 2004). Field experiments were conducted in a Finnish bedroom finished with untreated plasterboard and volume of 28.9 $m^3$. The plasterboard is hygroscopic, but has less capacity than wood, so one may anticipate equivalent results with wood.

RH was recorded at different ventilation levels, first with a basic model and then with the walls covered with 0.2mm polythene foil. A normal moisture level was established with mechanical humidification.

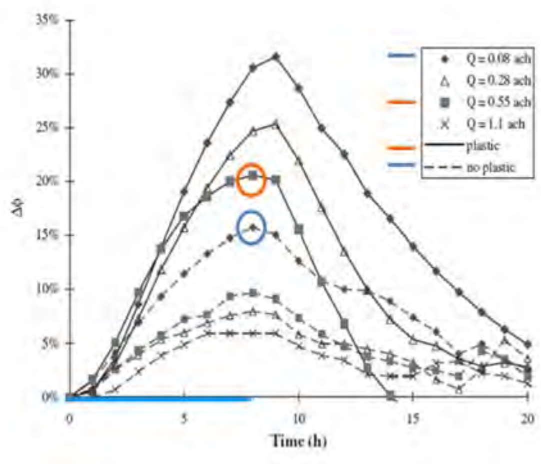


*Figure 22: Change in the relative humidity in the test room after the humidity generator was turned on for different ventilation rates with and without plastic. (Simonson, 2004)*

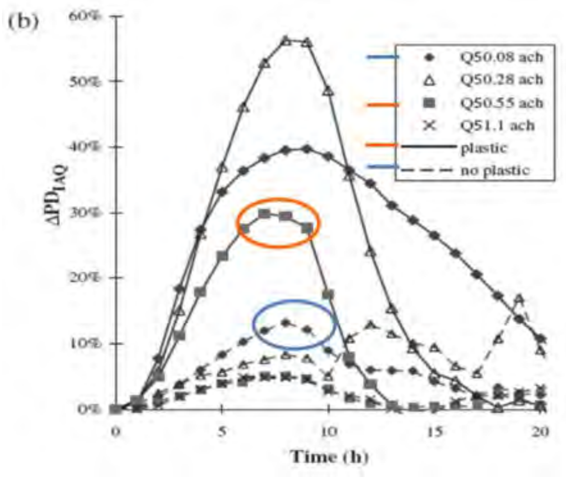


*Figure 21: Change in the calculated percent dissatisfied with warm respiratory comfort in the test room after the humidity generator was turned on for different ventilation rates with and without plastic, (Simonson, 2004)*

The results showed that an unventilated bedroom (0.08 ach) with hygroscopic cladding achieved a lower RH than a bedroom without hygroscopic cladding and air change of 0.55 per hour. It was also shown that during a user time of 10 hours the air quality was perceived as better in an unventilated bedroom with hygroscopic materials than in a normally ventilated bedroom with polyethylene foil.

# Appendix 4 Surface treatment of wood

## Introduction

The hygrothermal properties of internal wood cladding can be fully utilised by maintaining an untreated surface. However the lack of treatment will quickly lead to a yellowing of spruce and browning of pine, which may conflict with the brightness and aesthetic intentions of the material. A surface treatment of paint, oil or lye is therefore usually used. The surface treatment's vapour resistance is therefore essential to preserve the moisture regulating properties of the wood.

## Choice of surface treatment

Conventional paints (acrylic/alkyd/oil/polyurethane-based) have high vapour resistance, while other surface treatments are clearly more vapour open, such as *lime paint*, *glue paint*, *oil emulsion paint*, *silicate paint* and *silicon oil emulsion paint* (Geving, 2002). Of these, *lime paint* and *silicon oil emulsion paint* are generally inflexible and only suitable for use on mineral surfaces. This would also apply to many *silicate paints*, although special products are available that can be used on wood. Relevant surface treatments beyond this will consist of *glue paints* based on *casein glue* or *cellulose glue,* and *oil emulsion paint* based on vegetable oils. Lye treatment which is not film-forming is also an option.

Inadequate documentation about the product vapour resistance was revealed through a survey among current northern European manufacturers in April / May 2014. The following options were considered as appropriate on the basis of the examination:

- Untreated wood. Hardwood timber would prevent browning in some degree.
- Lye, with possibly lime additive added.
- Customized silicate paint. The product is pigmented with nanoparticles of titanium oxide to contribute to photo catalytic oxidation. This might cause some risk to the indoor climate.

## Detailing and individual zone treatment

The relevant treatments are matt and have limited washability. Therefore adaptations should be implemented to respond to this problem. These include careful detailing and appropriate individual zone treatment.

Interior surfaces of wood should be planed and optionally polished. Wood panels should be mounted vertically to collect a minimum of dust, profiling / lath panelling should be designed so that one can easily clean the space between panels. Panels should be placed on skirting boards having a minimum height of 100mm.

Individual zone treatment involving vapour permeable surface treatments should primarily be used in ceilings and the upper sections of walls.

## Experiences

A survey was conducted in June 2014 at three kindergartens/schools where one of the buildings had completely untreated surfaces and two had lime-lye treated surfaces. The staff in the former (untreated surfaces) were satisfied with the indoor environment, but reported that cleaning was relatively cumbersome. The staff at the buildings with lime-lye treatment were satisfied with the indoor environment, and reported few or no problems with cleaning.

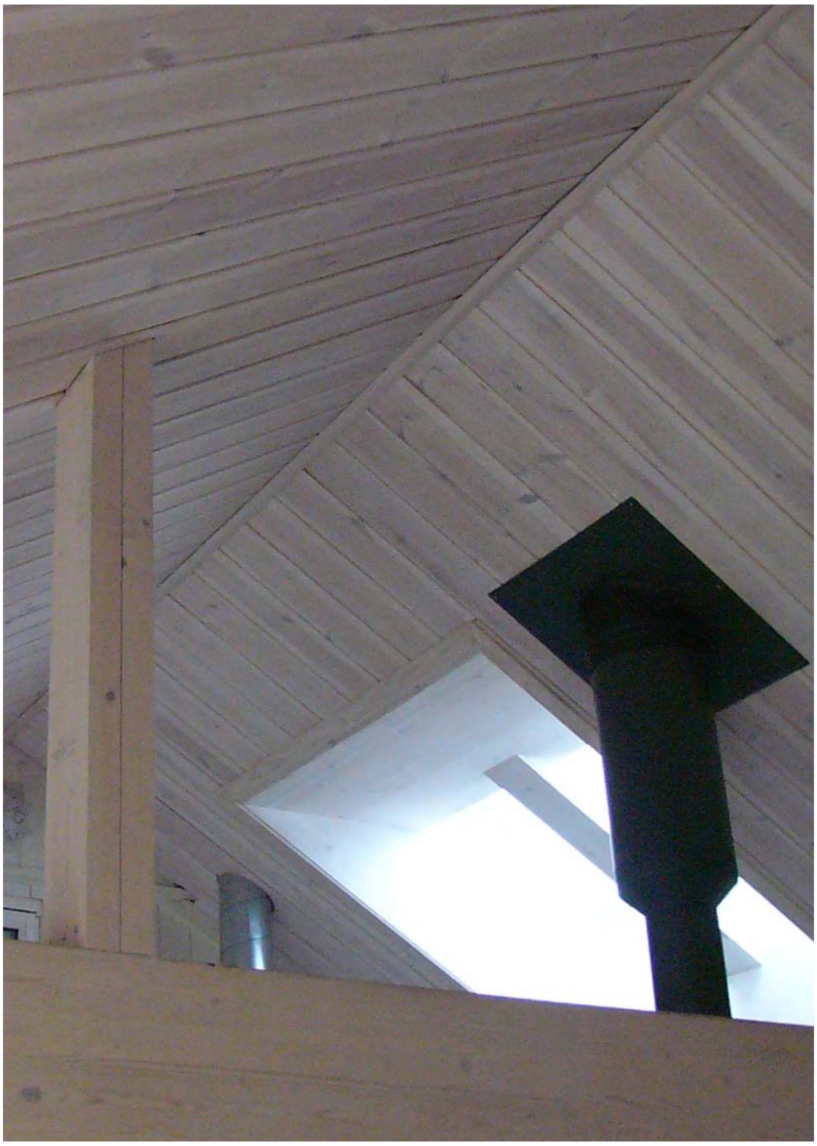

*Figure 23: Lime-lye treatment*

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