Envelope

a) Thermal transmittance (Heat)

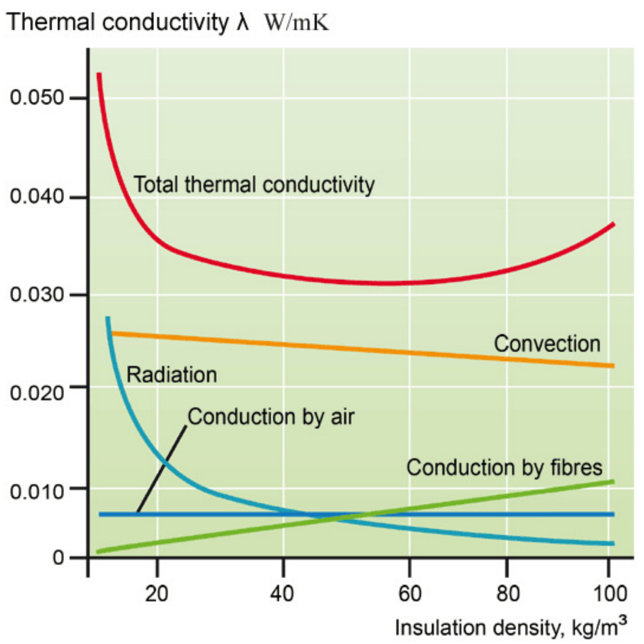
Thermal transmittance - better known as the U value - is the rate of transfer of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure.

When two systems are at the same temperature, they are in thermal equilibrium and no heat transfer occurs. When a temperature difference exists, heat tends to move from the higher temperature system to the lower temperature system, until thermal equilibrium is established. This heat transfer may occur in a building via conduction, convection or radiation. Thermal insulation is therefore designed to control the different components of heat transmittance.

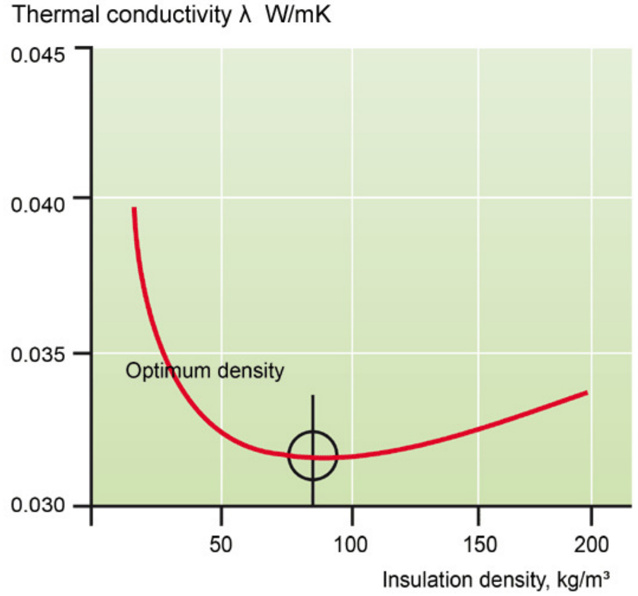
Conduction:	In a solid material when the molecules are excited by a heat source on one side of the material. These molecules transmit energy (heat) to the cold side of the material. Conduction occurs primarily through the foundation and framing members in buildings.
Convection:	Heated air becomes less dense and rises and cooler air is drawn in to fill the space left by the displaced heated air. Natural convection might occur, for example, in a very low-density mineral wool insulation layer during extremely cold winter days.
Radiation:	An object transfers heat to another object by releasing heat waves. For example, the Sun produces radiant energy that heats the Earth. Radiation into buildings occurs mainly through glass windows and doors.

Most heat loss occurs by conduction through the building components and by air leakage.

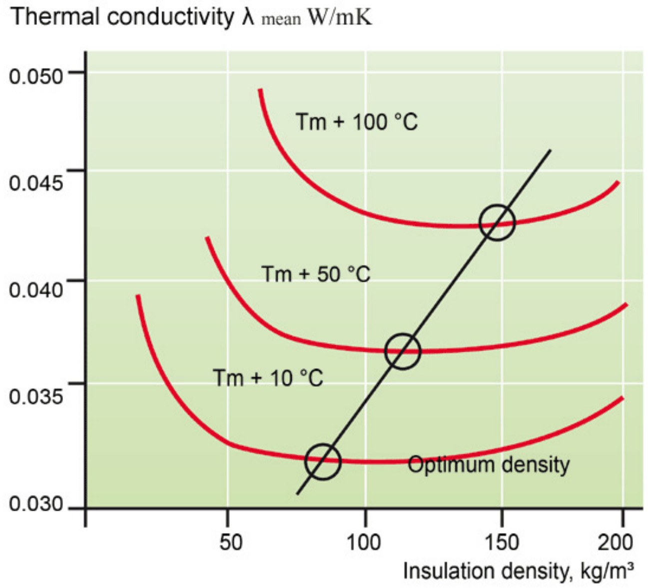
For mineral wool products, the thermal conductivity is the sum of four components:



- Thermal conductivity of the static air in the cavities between the stone wool fibres
- Thermal conductivity through the fibres
- Natural and/or forced convection by air movement in the wool
- Thermal radiation



- In low-density wool there is a lot of space for radiation and movement of air.
- The increase of insulation density reduces convection through the insulation and particularly the radiation in wool.
- Increasing insulation density increases conduction through fibres, but not by very much.



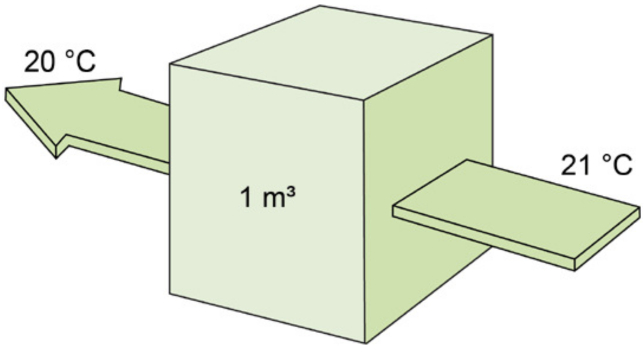
- Thermal conductivity increases when the mean temperature rises.
- For higher mean temperature, the optimal insulation density increases

All building materials have an individual thermal conductivity value expressed in W/mK. The lower the thermal conductivity value of a material, the better its insulating properties.

Material	Thermal conductivity, W/mK
Copper	401
Aluminium	237
Steel	60.5
Water	0.613
Wood	0.04–0.4
Stone wool	0.036
Air	0.0263

Table: Thermal Conductivities of Selected Materials at Room Temperature

The thermal conductivity or lambda value (λ) is a quantity of heat transmitted under steady-state conditions through the



unit area of the material of unit thickness in unit time when a unit temperature difference exists between its opposite surfaces.

The thermal conductivity of a material is measured using EN standards. It is by far the most important aspect of an insulating material. Stone wool insulation consists of up to 95 – 98 % static air from its volume, which makes it an excellent insulator. The lambda value for building insulation products is declared so that 90 % of the lambda measurements are within 90 % of the quoted value – hence ‘Lambda 90/90’. All thermal insulation products manufactured in accordance with harmonised European Standards have their lambda value tested and declared following the same methodology.

The thermal resistance (R) of a material and thermal transmittance (U) of a building construction can be calculated by using material thicknesses and thermal conductivity values.

Thermal resistance (R value)

A material's thermal resistance is obtained by dividing thickness (d) expressed in metres by thermal conductivity (λ) expressed in W/mK:

$$R = \frac{d}{\lambda}$$

Thermal resistance is expressed as m^2 K/W. The greater the value, the more effective the material’s insulation. Thermal resistance varies depending on material type, density and pore structure, moisture content and temperature difference.

Surface resistance

Surface resistance is a measure of the material’s surface inherent resistance to current flow and it does not depend on the physical dimensions of the material. It is impeded by the presence of a thin layer of relatively motionless air on the surface of the body. This offers resistance to heat flow and results in a temperature drop across the layer of air. The surface temperature varies depending on the mode of heat transfer.

- R_{se} = outside surface air resistance (moving air)
- R_{si} = inside surface air resistance (still air)

To calculate the total R value of anything that is composed of multiple materials, calculate the R values of each of the components, including internal and external surfaces.
Rtotal = R_{se} + R1 + R2 + R3 + R_{si}

Thermal transmittance (U value)

Thermal transmittance (U) defines the ability of an element of a structure, consisting of given thicknesses of material, air spaces, etc, to transmit heat under steady-state conditions.

It is a measure of the quantity of heat that will flow through a unit area in unit time per unit difference of temperature of the individual environments between which the structure intervenes.

This value is obtained as reciprocal of the sum of all the respective thermal resistances (R) of the component materials and the internal and external surfaces resistances:

Design U values are set against the targeted energy performance class or at minimum to satisfy local building regulations.

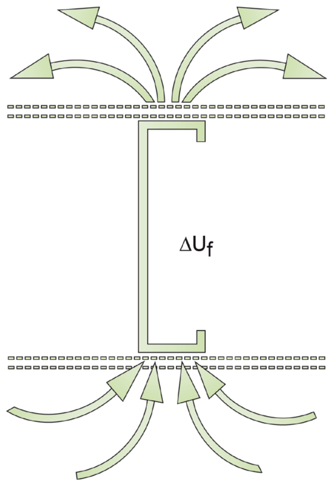
$$U = \frac{1}{R_{si} + R1 + R2 + R3 + \ldots\ldots Rm + R_{se}}$$

It is expressed as W / m^{2}K

In frame building systems, a substantial portion of heat loss occurs from conduction through the framing members, which have a lower thermal resistance than the insulation (thermal bridging).

Thermal resistance of the construction can be improved by reducing the effect of thermal bridging through the framed members. U value correction is not needed if:

- The wall ties across an empty cavity
- The wall ties between a masonry leaf and timber studs
- The thermal conductivity of the fastener, or part of it, is less than 1 W/(mK)



In U value analysis, include the effect of cold bridges in particular because the increase in thermal insulation also increases the relative impact of cold bridges. A significant reduction of cold bridges is obtained through optimal dimensioning of the building elements and careful planning of the connections.

Also evaluate and calculate the impact of geometric cold bridges, such as corners and window sills, in the design phase. By optimising the load bearing members, it is possible to reduce the number of frame structures and avoid the cold bridge effect.

Conduct U value calculation according to standard (for example, EN ISO 6946 in EU). From the standard you are able to find following information, which has an effect on U value calculation:

- Surface resistances (colour, wind speed, non-planar surfaces)
- Thermal resistance of ventilated and unventilated air layers (convection effect)
- Total thermal resistance calculation for homogeneous, inhomogeneous (upper R_{max} and lower R_{min} limits of the resistance) and tapered layers
- Corrections (ΔU) → air gaps ΔU_g + mechanical fasteners ΔU_f + inverted roofs ΔU_r

Passive houses are built using different structural systems. However, the small heat need requires a thermal insulation level significantly better than normal. Indicative objective values for the total heat transfer coefficient and features in the outer shell are given below:

- Exterior wall 0.07–0.1 W/m^{2}K
- Base floor 0.08–0.1 W/m^{2}K
- Roof 0.06–0.09 W/m^{2}K
- Window 0.7–0.9 W/m^{2}K
- Solid window 0.6–0.8 W/m^{2}K
- Entrance door 0.4-0.7 W/m^{2}K

Heat loss

Calculate heat loss through any given structure by multiplying the surface area by the U-value of the structure and then multiply that by the temperature difference (commonly represented by the Greek letter Delta) between the inside and outside.

$Q = A*U*(T_{inside} - T_{outside})*h$ or $Q = A*U*\Delta T*h$

When a structure is made of different materials, such as a wall that contains windows and a door, calculate the heat loss through each of the components separately, then add their heat losses together to get the value for total heat loss.

$Q_{wall} = Q_{framed\ area} + Q_{windows} + Q_{door}$

The greater the temperature difference, the greater the gradient – the driving force behind the flow of heat, and the greater the potential for heat loss.

In passive buildings, energy savings correspond to thick thermal insulation layers.

- The wall's structural thickness can be 400 – 600 mm depending on the structural principle and materials.
- In roof constructions, where insulation is relatively easier, the insulation thickness can be up to 700 mm.
- Insulation thickness in vented floors can be 500 mm but in ground-supported structures, frost protection determines the safe thermal insulation of floors.

Finland has experience in 250 – 300 mm thermal insulation of ground-supported floors. Current frost protection instructions cover insulation thicknesses of up to 200 mm. The risk of the foundations becoming frozen depends on the building site and soil conditions. The heat loss of a well-insulated floor is so small that it cannot prevent the ground below the foundations from freezing without measured frost protection in shallow foundation structures.

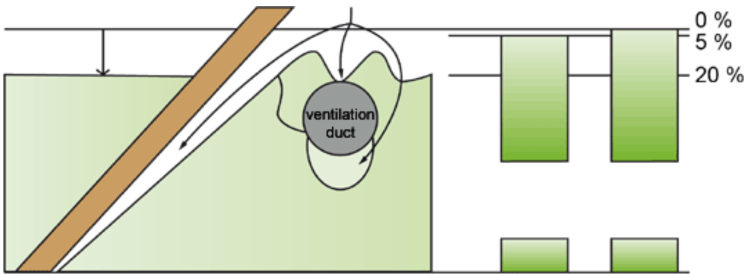
Preventing foundations from freezing is usually based on frost insulation in foundations and heat loss in the ground-supported base floor. Thermal insulation in the base floor of a passive house is so good that heat loss in the base floor does not help in frost protection. The frost risk of the construction site must be identified using soil studies, and frost insulation of foundations must be measured to correspond to the risk.

Heat loss due to settling of blowing wool

Blown thermal insulation is an in-situ type product based on granulated mineral wool which is blown into an attic with a blowing unit. Blown insulation can also be used for the insulation of walls.

Blown insulation tends to settle over time, so for stability reasons it is required that the settlement over time does not exceed the design values. Settlement is caused both by vibration and temperature and humidity fluctuations over seasons.

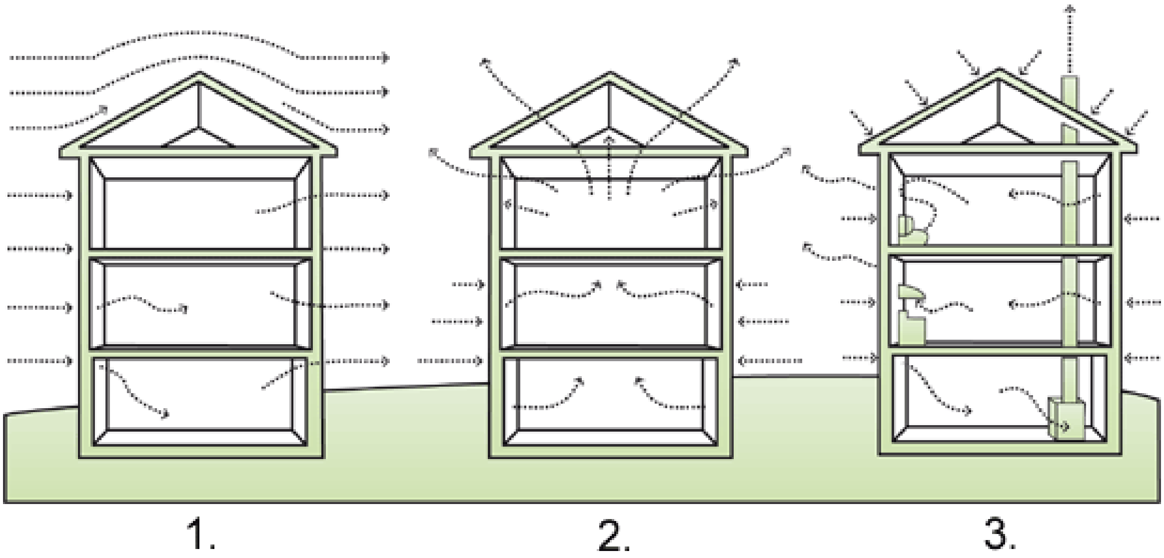
In the drawing you can see the effect of insulation settlement in practice. Settlement can cause gaps and cavities in attic insulation so that cold air gets into structures and the risk of condensation increases.



Long experience shows that PAROC stone wool settlement is about 2 – 3 %. This means that stone wool insulation do not cause any risks in attics due to settling. Paroc always installs an insulation layer that is 5% thicker than required.

b. Airtightness

The movement of air in a building's envelope is caused by temperature or pressure differences between the exterior and interior. This is caused by the following effects:

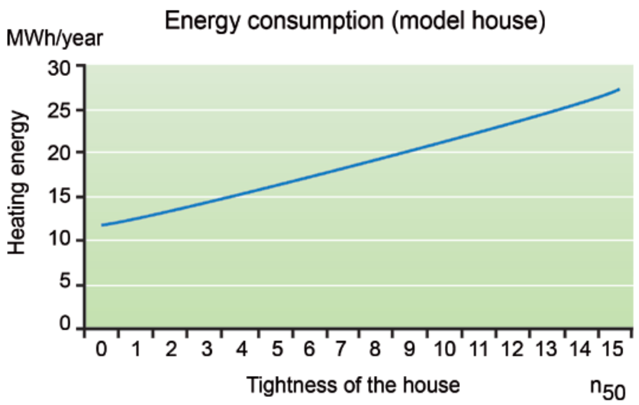


1. Wind effect	Wind pressures influence air leakage, forcing cold air in through cracks on the windward side and warm air out of most of the rest of the structure.
2. Stack effect	The building acts like a chimney; warm air rises and can escape through openings in the upper parts of the house and cold air is drawn in around floors and baseboards to replace the escaping warm air.
3. Ventilation effect	Mechanical and passive ventilation systems intentionally exchange indoor air with 'fresher' outdoor air. Pressurised systems blow air into the building, depressurised types blow air out and balanced systems bring in as much as they push out.

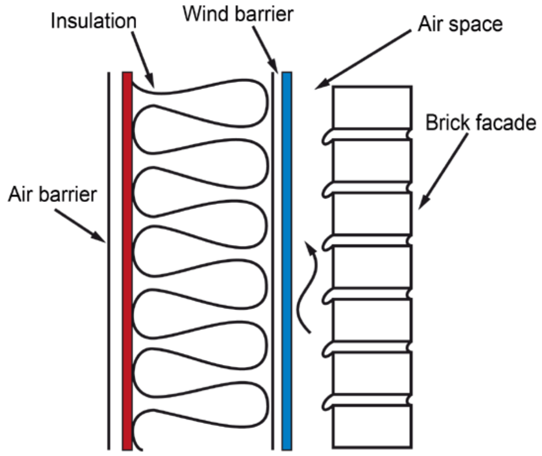
The control of air movement through the building envelope is critical in reducing heat loss and preventing moisture build-up. Ex-filtrating air carries both heat and moisture (in the form of water vapour) to the outside. Water vapour (as carried in the air) can condense within the building envelope and is a primary cause of structural failure in a building.

The airtightness of the building envelope can be measured according to the standardised pressure test EN 13829, by subjecting the building to 50 Pa overpressure and evaluating the air exchange rate of the building. The air leakage rate in the building should not exceed 1 per hour.
Below are some typical air leakage rates for different buildings:

- Passive building n50 = 0.6
- Tight building n50 = 1
- New buildings (Finland) n50 = 3 – 4
- Normal tightness n50 = 5...10 (typical old Finnish house)
- Leaking construction n50 = 15



The requirement level for airtightness is considerably more stringent and the rate required for a passive building (< 0.6 1/h) is becoming standard practice. The air seal must be planned in such a way that it allows uninterrupted installation throughout the outer shell.



- An air/vapour barrier prevents air/water vapour from penetrating through the envelope. Always locate it on the warm side of the envelope.
- A wind/weather barrier on the outside of the envelope stops wind from blowing through the insulation and protects the envelope from rain and snow.

An air/vapour barrier

A vapour barrier is located behind the internal wall board. Protect the vapour barrier by using a 45 – 70 mm thick installation layer directly behind the inner wall board. The vapour barrier stops air and moisture movement into the construction. It is important you ensure that the vapour barrier is continuous and tight around all penetrating installations.

The air permeability of the air/vapour barrier material should be < 3×10^{-6} m^3 / m^2 s Pa. If plastic foil is used, sufficient overlap must be provided for the joining and the work order designed correctly to have the joining overlap available through obtrusive structures such as partitions. Place the overlap between two firm surfaces allowing a pressed connection.

Place the vapour and air barrier recessed from the internal surface to allow installation space for the electrical wiring.

Avoid penetrations through the air seal. If this is not possible, seal penetrations through massive structures with caulking, and use a collar or flange where the penetration is through foil.

A wind barrier

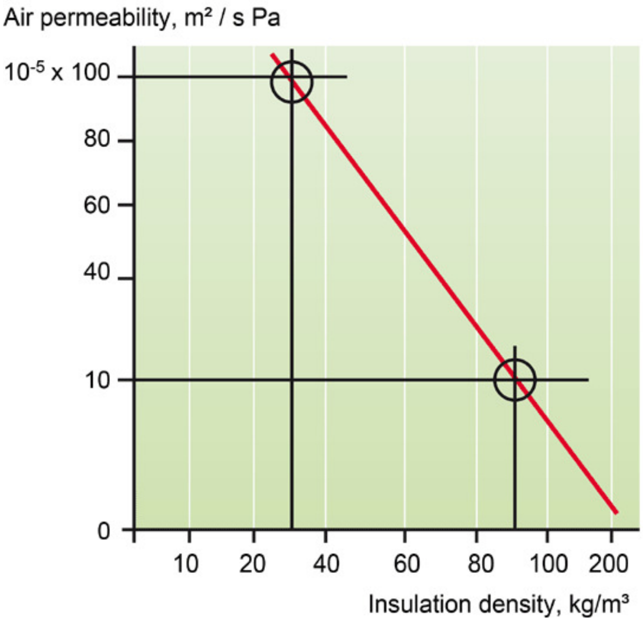
A wind barrier is located behind the exterior cladding and it is needed because in many cases the exterior cladding is not airtight. Use a wind barrier to stop wind from blowing through or around the insulation. Ensure that the wind barrier does not act as a vapour barrier, trapping moisture inside the envelope. The wind barrier should be wind proof but it should allow the passage of water vapour. The water vapour resistance of the wind barrier should be at least five times smaller than air/vapour barrier resistance.

Wind protection requirements for energy efficient buildings do not differ from the requirements of a standard building. However, proper wind protection plays a major role in a building's energy efficiency. Check local building requirements for the maximum air permeability, including all joints. For example, in Finland, the maximum air permeability of a wind barrier is < 10×10^{-6} m^3 / m^2 s Pa.

Standard House (indicative values)		**Low Energy House (indicative values)**		**Paroc Passive house concept (indicative values)**	
U value, W/m^2K	Insulation thickness	U value, W/m^2K	Insulation thickness	U value, W/m^2K	Insulation thickness
Roof insulation					
0.15	260 - 310 mm	0.08 - 0.12	300 - 400 mm	0.06 - 0.09	> 450 mm
External wall					
0.24	150 - 175 mm	0.13 - 0.15	230 - 300 mm	0.07 - 0.1	> 300 mm
Floor					
0.2	100 - 150 mm	0.13 - 0.17	150 - 250 mm	0.08 - 0.1	> 300 mm
Windows					
1.4		1.0 - 1.3		0.7 - 0.9	
Mounted windows					
				0.6 - 0.8	
Doors					

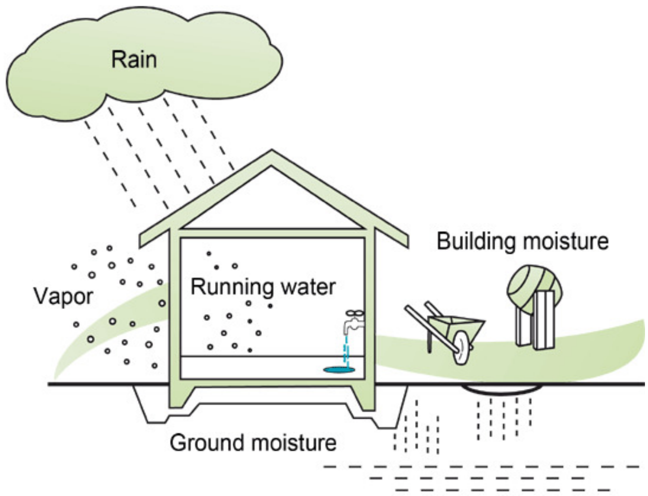
Doors		
1.4	0.9 - 1.2	0.4 - 0.7
Air-tightness rating		
< 4	< 1	< 0,6
Annual heat recovery rate in ventilation		
30 %	> 60%	> 75%

Effect of stone wool insulation density on its air permeability
The ability of mineral wools to insulate is based on static air between the fibres. Air movement in the insulation layer weakens the insulation capacity. An increase of insulation density reduces the air movement and improves insulation capacity. The lower the density, the better the wind barrier needed.



c. Moisture

One of the keys to building durable housing in northern climates is the control of moisture in all its phases: solid, liquid and gaseous.



There are four basic mechanisms by which moisture enters or leaves a building:

- Rain penetration (wind barriers)
- Air leakage (air barrier)
- Diffusion
- Capillary from the ground

Water vapour comes into indoor air from normal everyday living (see the table below). The amount of water produced from normal household activities can be quite considerable.

Water vapour source (average house/day)	Approximate water generated (in litres/day)
4/5 people asleep:	1,5

2 people active:	1,6
Washing and drying clothes	5,5
Cooking	3
Shower	0,5

Relative humidity

Air can hold different amounts of moisture depending on the air temperature. Actual vapour pressure is a measurement of the amount of water vapour in a volume of air and increases as the amount of water vapour increases.

Air that attains its saturation vapour pressure has established equilibrium with a flat surface of water. This means, that an equal number of water molecules are evaporating from the surface of the water into the air as are condensing from the air back into the water.

The amount of water vapour in the air is usually less than required to saturate the air. The relative humidity is the percentage of saturation humidity, generally calculated in relation to saturated vapour density.

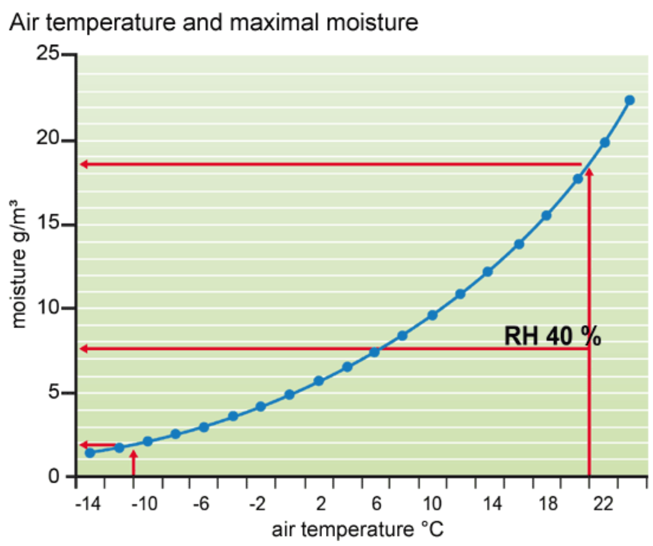
$$Relative\ humidity = \frac{Actual\ vapour\ density\ /\ pressure}{Saturation\ vapour\ density\ \ pressure} * 100\%$$

$$\varphi = RH = \frac{p}{p_k} * 100 = \frac{v}{v_k} * 100$$

The most common unit for vapour density is g/m^3.

For example, if the actual vapour density is 10 g/m^3 at 20°C temperature compared to the saturation vapour density at that temperature of 17.3 g/m^3, then the relative humidity is:

$$Relative\ humidity = \frac{10g/m^3}{17.3/m^3} * 100\,\% = 57.8\,\%$$



Relative humidity (RH 40 %) means that there is 40 % of the maximal moisture in the air at a certain temperature

Dew point

The dew point is the temperature at which water vapour transforms into liquid water. This is a function of both temperatures and the amount of moisture in the air.

If we have a dew point of 10ºC, any surface in the room that reaches this temperature will leave liquid water on it. To prevent this condensation, we can either raise the surface temperature or lower the relative humidity.

Water vapour will only condense onto another surface when that surface is cooler than the dew point temperature, or when the water vapour equilibrium in air has been exceeded.

The easiest method to control damage from water vapour and moisture is to reduce the amount generated.

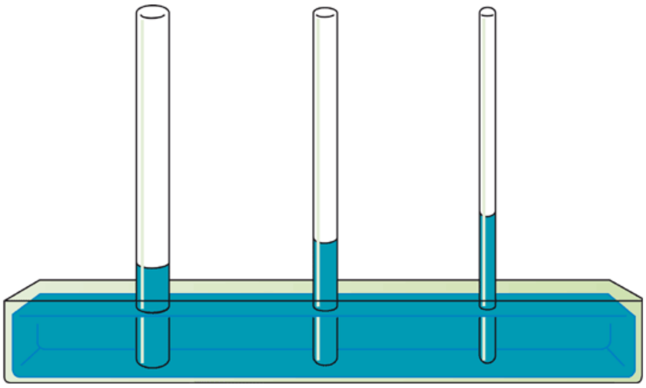
Diffusion

Diffusion occurs due to differences in vapour pressure which result from differences in the concentration of water vapour between two locations. In the heating season, this vapour movement carries water vapour through the building envelope where it can condense on cold surfaces. Vapour barriers are used on the interior side of the envelope to prevent the moisture movement.

All materials allow water vapour to pass through them to some degree. Condensation will not usually occur as long as two-thirds of the insulating value of the wall is located outside the vapour barrier. In the far northern region, however, up to 80% of the insulation value may be required outside the vapour barrier.

Capillary moisture

Capillarity is the ability of a liquid to flow in narrow spaces without the assistance of, and in opposition to, external forces like gravity. This phenomenon occurs, for example, in soil.



In the same way that water moves upwards through a tube against the force of gravity; water moves upwards through soil pores, or the spaces between soil particles. The height to which the water rises depends on pore size.

Common areas where capillary rise is present are the footing into the foundation wall and capillary suction of water behind a siding. Capillarity can be controlled by sealing the pores or making the pores very large. Non-hygroscopic stone wool works also as a capillary break between the soil and foundation.

Design hints for building moisture safe envelopes

- Balance wetting, drying and storage

Practical Rules
- Provide a continuous plane of rain control, including each enclosure detail
- Provide continuous air/vapour barriers
- Provide insulation to control condensation problems
- Allow drying of built-in and accidental moisture – beware of drying retarders

Consideration should also be given to the drying capacity of structures. In the design, structure bound moisture must be given a route to dry out. A building should be protected against moisture by designing drainage of surface water and capillary cut to keep the foundation dry. Driving rain should be taken into account in the design of the structural details; for example, a window sill joining.

d. Windows

Windows are the part of the building envelope with the highest thermal transmittance. Therefore, in the design of a building, give attention to the performance, size and direction of the windows. Windows gain and lose heat in the following ways: by direct conduction through the glass and frame, by thermal radiation into a building from the Sun and out of a building from room temperature objects, and by air leakage through and around them.

The total thermal transmittance, U value (W/m^2K), is used to determine the rate at which a window conducts non-solar heat flow. U-value ratings determined by the European Standards represent the entire window performance, including frame and spacer material; the lower the U value, the more energy-efficient the window.

The area of windows is typically 15 – 20 % of the floor area. Even if the windows have a good low-energy level (U -value < 0.8 W/m^2K), they must not be too high. Even a good window cannot prevent the feeling of draught caused by high windows. For thermal habitability, 1.8 meters can be regarded as the limit for the height of windows. In a cold climate, windows should not be at floor level in order to ensure habitability and airtight structural details.

Air leakage, the rate of air infiltration around a window in the presence of a specific pressure difference across it, is affected by the joining details between the parts of the window assembly.

Total solar radiation transmittance, g value, is the fraction of solar radiation admitted through a window transmitted directly and/or absorbed, and subsequently released as heat inside a building. The lower the g value, the less solar heat it transmits and the greater its shading ability. A window with a high g value rating is more effective at collecting solar heat gain during the winter. A window with a low g value rating is more effective at reducing cooling loads during the summer by blocking heat gained from the Sun. Therefore, the g value needed for a window should be determined by climate, orientation and external shading.

Selective coating is a transparent metal or metal oxide layer which transmits and reflects the different frequencies of radiation selectively. Selective coating reduces the rate of radiation through the glass and improves the thermal performance of the window.

A gas filling other than air (argon, krypton and xenon) can be used to improve the energy performance of a window. Spacer material also plays an important role.

Condensation of the outside moisture to the external surface of a high performance window is a new phenomenon. Condensation is caused by the temperature drop of the external surface below the dew point of the outside air. The temperature drop is the result of radiation exchange against the clear sky. In fact, the same happens for standard windows but is compensated for by thermal leakage.

Shading windows reduces the Sun’s thermal load by up to 60 %. Moreover, shading reduces condensed moisture on the outer surface of windows during cloudless nights. Condensation is caused by the window surface cooling down because of thermal radiation; thus, it is also a sign of the good thermal qualities of windows.