Implementing the Results of Ventilation Research
16th AIVC Conference, Palm Springs, USA
19-22 September, 1995

The Indoor Air Quality and the Ventilation Performance of Four Residential Buildings with Dynamic Insulation

J T Brunsell

Norwegian Building Research Institute, P O Box 123
Blindern, N 0314 Oslo, Norway

THE INDOOR AIR QUALITY AND THE VENTILATION PERFORMANCE IN FOUR RESIDENTIAL BUILDINGS WITH DYNAMIC INSULATION

SYNOPSIS

Dynamic insulation has been used in non domestic buildings for 20- 30 years in order to reduce the heat loss and to bring preheated air into the buildings. Dynamic insulation means a construction where the air is being forced through the insulation, usually from the colder outside air into the heated building.
The Norwegian Building Research Institute has been engaged to evaluate 12 row houses, with dynamic insulation used in the roof, which has been built in the Oslo area. 4 of the houses were monitored over a period of time. In two of the houses the thermal performance were monitored when the houses were new. In the other two the indoor air quality, the ventilation performance etc. were measured after two years of occupation. The paper presents the results from these measurements. The main conclusion from the work is that dynamic insulation gives a good indoor climate with less conduction heat loss than an ordinary construction with the same thickness of insulation.

THEORY

The air-flow is normally forced the opposite direction of the conduction, thus the term *contraflux insulation.* When the airflow has the same direction as the conduction, *proflux insulation*, there is a big risk of moisture condensation inside the construction. All the tests described in this paper is carried out with contraflux insulation.

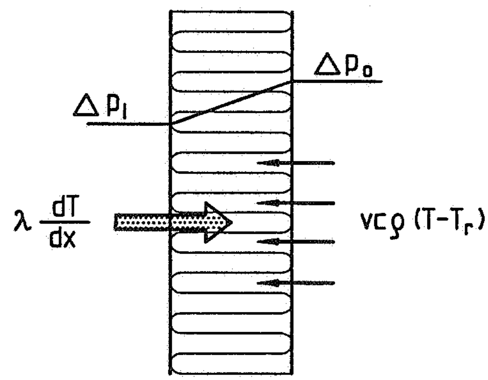

Figure 1.
Direction of conduction and convection in a contraflux insulation.

The conduction and the convection heat flow can be described mathematically as follows:

$$q_d = \lambda \frac{dT}{dx}$$

$$q_v = v\rho c_p\ (T-T_r)$$

In a steady-state situation Anderlind (1) first showed that the temperature distribution in a homogeneous insulation layer can be described as:

$$T = T_u + (T_i - T_u)\frac{e^{-\frac{ax}{d}} - e^{-a}}{1-e^{-a} + \frac{a}{b-a}}$$

where $a = \frac{v\rho c_p d}{\lambda}$ and $b = \frac{\alpha_i d}{\lambda}$

The concept "dynamic U-value" can be defined as the U-value of a construction with "static" insulation with the same conduction heat loss as the construction with the dynamic insulation. For a homogeneous insulation layer the dynamic U-value in the steady state situation can be shown to be:

$$U = \frac{\lambda}{d} \cdot \frac{a\, e^{-a_1}}{1-e^{-a} + \frac{a}{b-a}}$$

The U-value as a function of the air velocity and the thickness of the insulation is presented in figure 2.

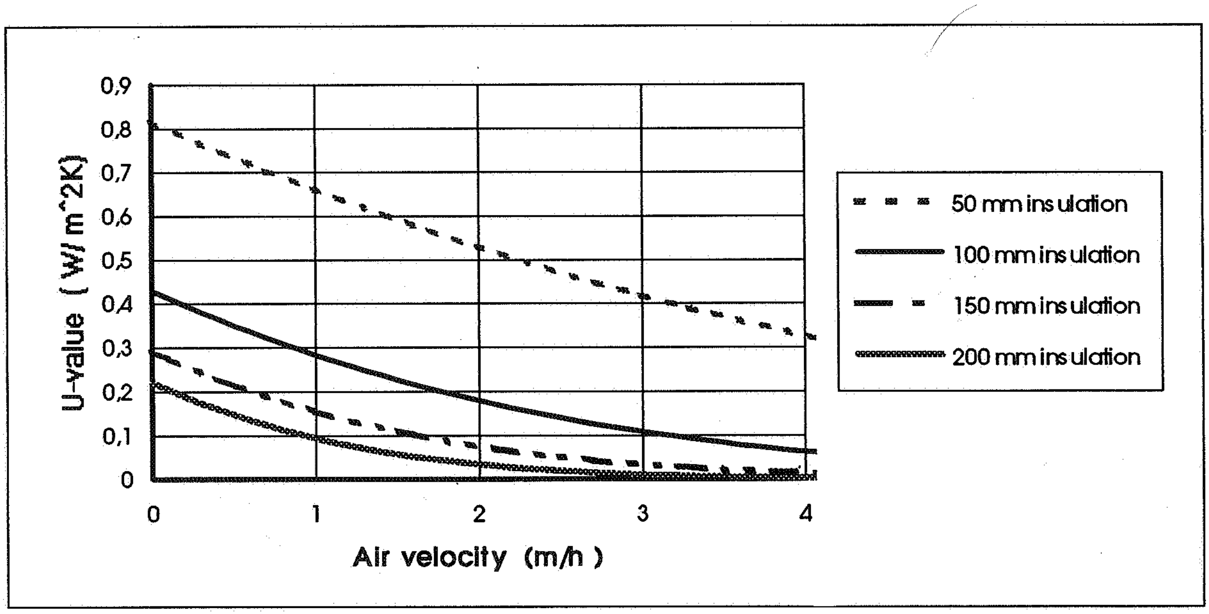

Figure 2
"Dynamic U-value" for a construction with 50 -200 mm dynamic insulation as a function of the air velocity.

FIELD EXPERIMENTS

The construction of the 12 houses with dynamic insulation in the roof is shown in figure 3. Several strategies can be used to force the air through the insulation:

1. Overpressure in the attic
2. Underpressure inside the house
3. Combination of 1. and 2..

The necessary and acceptable pressure difference will also vary with the different strategies and type of houses.

For the 12 row houses the strategy 2. was chosen.
The underpressure was planned to be 10 Pa. We considered 10 Pa to be the highest pressure difference that could be acceptable for the users (opening of windows and doors etc.). 10 Pa was also considered enough to avoid the wind causing a change of the flow direction through the roof or the walls more than 5 % of the time. The velocity through the insulation with 10 Pa pressure difference should be 2 m/h which should give a ventilation rate alone of 0.8 ach. If the n_{50} value, based on leakages from the rest of the house, was less than 1.0 ach, an airflow which corresponds to about 0.3 ach would come through the leaks in the walls and the floor at a pressure difference of 10 Pa. Together this will give a total ventilation rate of 1.1 ach.

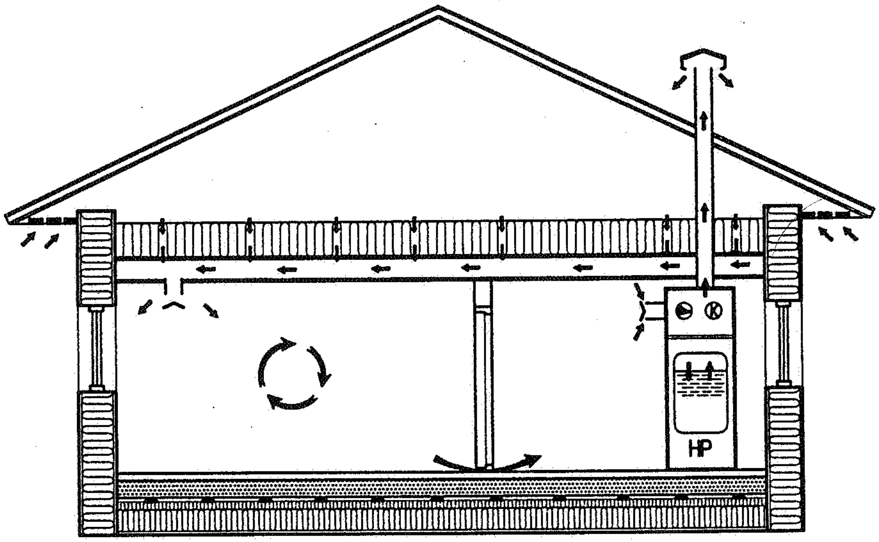

Figure 3.
The 12 row-houses have dynamic insulation in the roof. The outside air is sucked into the attic and then down through the insulation and into the house through inlets. The driving force is an underpressure inside the house created by fans in the heatpump which also transfer the heat from the exhaust air to the hot water supply. The houses were built without any influence from the evaluation group.

The following parameters were measured in the houses (not all the parameters were measured in all of the four houses):

- Ventilation rate measured with tracer gas technique inside and in the attic
- Volume flow through the outlets
- Temperature inside, outside and the profile through the insulation
- Pressure differences between the outside, the attic, through the insulation and the inside
- Wind speed and wind direction
- TVOC, CO and CO_2 concentrations outdoors, in the incoming air and in the indoor air
- Number of particles outdoors and in the in incoming air
- Concentration of fungal propagules

Ventilation rate measurements were carried out with the constant concentration method using Brüel and Kjær equipment model 1302 and 1303. We had 6 channels for dosing and 6 for sampling. Values for the tracer gas measurements were logged every minute, then averaged values for 10 minutes were stored.
CO-, CO_2- and TVOC- concentration is continuously measured with the same instrument.

Values for temperature, pressure differences, wind speed and wind velocity were logged every 10th second and then the averaged values for 10 minutes were stored.

Concentration of fungal propagules is measured with a BIAP Slitsampler with DG18.

RESULTS

House 1 were occupied by the owners, an elderly couple, during the measurements. After the termination of the measurements and all the equipment were removed, they informed us that they had tried to air out the tracer gas by opening windows and doors. The pressure difference across the thermal envelope disappeared of course during these periods. In addition we had some problems with the tracer gas equipment and therefore there are no results from these measurements in house 1.

House 2 was unoccupied during the measurement period which can be divided into two parts. During the first period we did only tracer gas measurements inside the house. During the second period we had tracer gas measurements in the attic and sampler tubes in the insulation, in the air inlet and inside the livingroom.

House 3 was occupied by an elderly woman. When the measurements started we realized that the flow through the outlets were only 40 % of the planned value. This was due to the filter in front of the heat pump which had not been changed for two years and because the fan had been adjusted because of noise. A new filter was installed and the fan was adjusted the last day of the measurement in house 3 and the ventilation rate went up from about 0.4 ach to about 1.0 ach.

House 4 was also occupied by an elderly woman.

House 1 and 2 were measured 4 months after the houses were finished while house 3 and 4 were monitored after 2 years.

The main results are given as averaged values in table 1.

Table 1.
Averaged values from all the four houses. Each measurement lasted from 5 to 8 days.
1): Measured with Brüel and Kjær model 1302
2): Measured with adsorption for two hours on tenax TA and analysed with GC - MS.
3) 3 other of the 12 row houses were measured and the n_{50} values were: 4.8, 4.4, and 4.6 ach at 50 Pa pressure difference
- means either that there has not been measured any values or that the measurements were unsuccessful

Parameter	House 1	Outs.	House 2 -1	House 2 - 2	House 2 Attic	House 3	Outs.	House 4	Outs.
Temperatures(C)	21.1	5.3	-	25.6	13.9	24.1	1.2	22.3	-7.9
Temp air inlets (C)	18.0	-	-	-	-	21.9	-	12.0	-
Pressure diff (Pa)	8.2	-	-	6.2	-	3.9	-	10.4	-
CO livingr. mg/m^3 1)	2.6	-	3.3	3.4	2.7	-	-	-	-
CO_2 livingr. mg/m^3 1)	1170	-	954	1163	910	1127	784	1125	1048
TVOC livingr. mg/m^3 1	7.9	-	11.8	11.2	6.3	7.2	5.0	5.0	5.0
TVOC inlets µg/m^3 2)	-	-	-	-	-	225	380	289	380
Air tightness, n_{50}, 3)	-	-	4.2	-	-	4.2	-	-	-
Air change rate	-	-	0.58	-	2.0	0.54	-	1.09	-

Concentration of gas contaminants

Together with the tracer gas measurements some gas contaminants were monitored as well. The results do not indicate that outside air, going through this kind of insulation, brings contaminants from the insulation into the house as some have feared. This depends on the kind of insulation and other materials which are used in the dynamic construction.
These measurements are not fully analysed and will therefore not be discussed further in this paper.

Particles

When the houses were new the total concentration of particles in the incoming air was measured. In addition the amount of particles was measured in house 3 and after two years of operation.

Table 2.
Concentration of particles in the air inlets in house 5 and 6.

	House 5	House 6
Cons: - 2.5 µm (µg/m^3)	16.6	4.4
Cons. 2.5 - 15 µm (µg/m^3)	4.4	4.8
Total: - 15 µm (µg/m^3)	21	9.2

After 2 years the number of particles in house 3 and 4 was counted and results are shown in table 3.

Table 3.
Number of particles in house 3 and 4 and outside measured in January 1995, two years after the houses were new.

	House 3, inside	House 3, air inlet	Outside	House 4, inside	House 4, air inlet	Outside
Number of part.-2.5µm	41200	5850	86500		19800	249500
Number of part 2.5-15µm	1100	9	325		50	400

Fungal propagules

The concentration of fungal propagules was measured in house 3 and 4. The concentration, which is given in Colony Forming Unit (CFU), was measured in the air inlet, in the attic and outside. The results are given in table 4.

Table 4
Concentration of fungal propagules

	House 3 air inlet	House 3 attic	House 3 outside	House 4 air inlet	House 4 attic	House 4 outside
Colony forming units (CFU)	0	36	39	21	39	42

Tracer gas measurements

The ventilation rate for the Houses 2, 3 and 4 are given in figure 4.

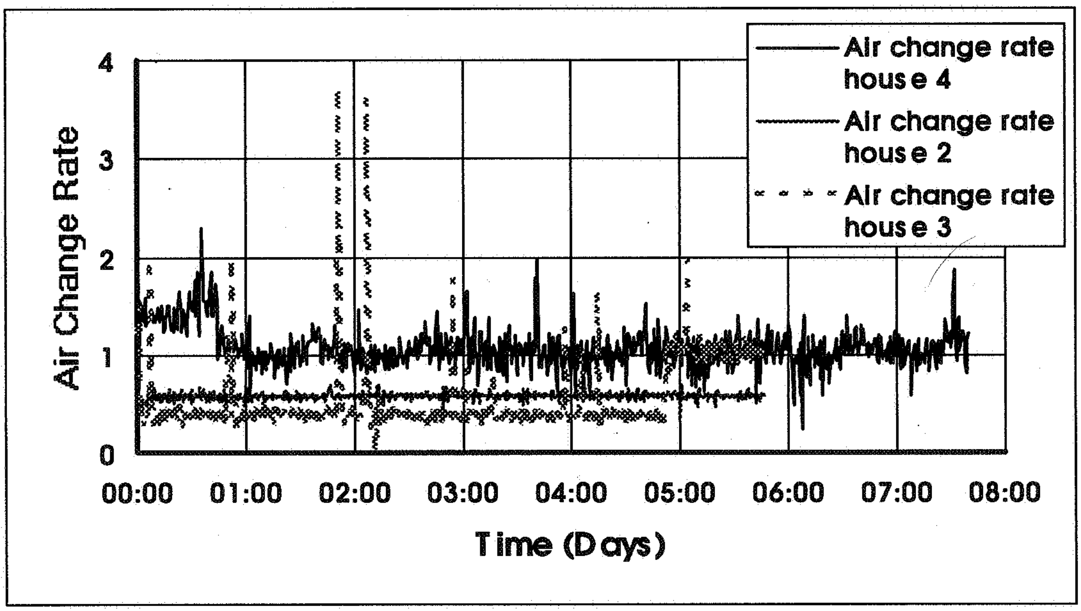

Figure 4
Ventilation rate for house 2, 3 and 4. The first half day in house 4 the pressure difference was not adjusted to the right level. For house 3 the pressure difference and therefore the air change rate was right only the 5th day.

The ventilation rate for the whole house 2 is rather constant as expected. With an underpressure of 6-7 Pa there must be a wind speed above 3-4 m/s towards a wall to change the flow direction through the leaks in the leeward wall and change the air change rate significantly.

In house 4 the average pressure difference was higher, 10.4 Pa, and hence the higher ventilation rate. Figure 4 also show the difference in the variation of the ventilation rate between an unoccupied house and an occupied house.

Pressure differences, temperatures and wind speed

These measurements were carried out in order to better evaluate the performance of the "dynamic construction".

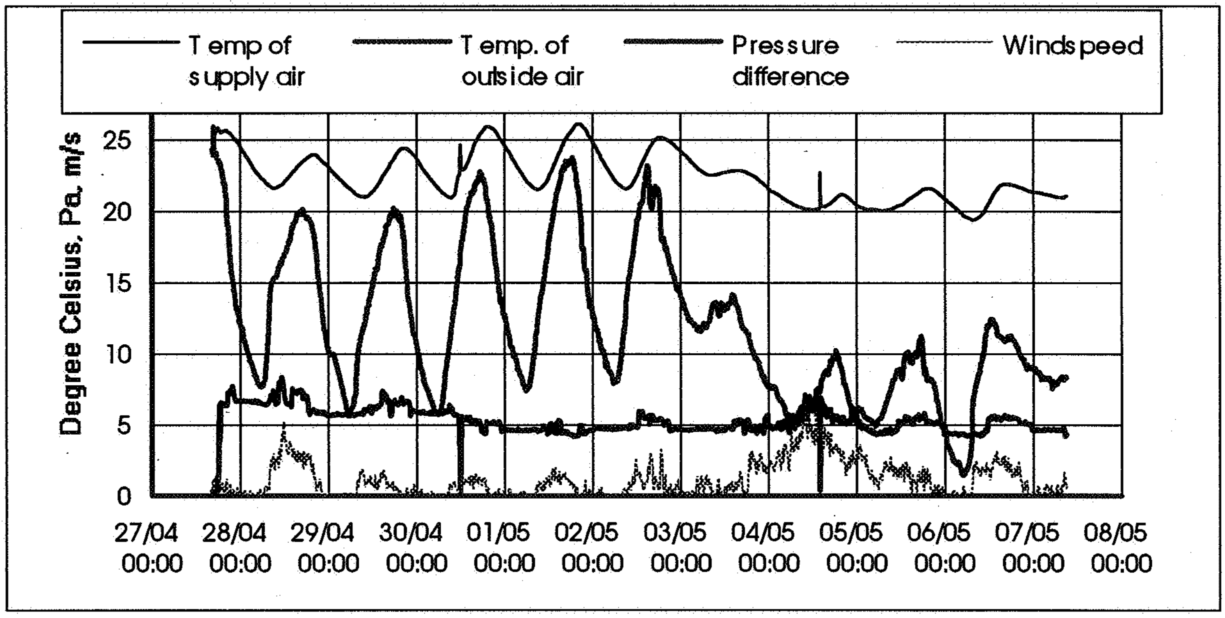

Figure 6
Temperature of supply air, pressure difference between the inside and the attic, temperature of the outside air and wind speed measured for house 2. The pressure difference is smaller than for house 1 but it is stable around 5-6 Pa.

For both house 1 and 2 we had 2 columns with temperature sensors through the insulation. For all the four columns we found the curved temperature profile which correspond to the theoretical curve.

DISCUSSIONS

From the measurements in house 1 and 2 it is clear that a smaller proportion of the total ventilation rate is coming through the roof than planned. There are two reasons for this:

- The n_{50} value is higher than planned
- There are leaks from the air layer and out through the walls

The measurements in house 1 and 2 also show that the total flow rate was smaller than planned even if the houses were leakier than planned. The reason for this is bad or none adjustment of the fan and all the outlets and inlets after the houses were completed.

The strategy for bringing in the air to the house has been to establish an underpressure inside. Since the houses are leakier than expected, more air will be sucked through the leaks. To avoid this, one action can be to establish an overpressure in the attic. This will give the possibility also to clean the air before it enters the insulation.

From the temperature measurements on both sides of the insulation and inside the insulation it is possible to calculate a "dynamic U - value" for house 1 and 2. The average U-values for the roofs for the measured periods for these two houses are:

House 1 $U = 0.10\ W/m^2{}^\circ K$
House 2 $U = 0.06\ W/m^2{}^\circ K$

The periods are too short however to find a representative "dynamic U-value" for the roofs. The values indicate though that the heat loss through the roof have been reduced with 55 % and 73 % respectively for the two houses compared to the conduction heat loss through a similar construction with static insulation. The U-value without any convection is $U = 0.22\ W/m^2{}^\circ K$.

Air Quality

The results from these measurements show that the incoming air in these houses with dynamic insulation have a very good quality after two years of operation. The measurements show that there are no mould growth in the insulation. The content of particles in the air which has passed the insulation is significantly lower than in the outside air. Since the particles will be filtered in the insulation there is a possibility that this could cause problems after some years of operation . One could fear that there would be a growth of bacteria and mould which could result in spread of contaminants, e.g. endotoxin and spores, to the indoor environment. This has, however, not been found in this project (endotoxin is not measured in this project) nor been reported by others . The reason might be one or several of the following facts:

1. Buildings with dynamic insulation has been used for only 25 years.
2. The volume flow, through the insulation is very low.
3. There have not been many evaluations of indoor air quality of the oldest buildings

Re. 1:
There are older buildings with dynamic insulation than 25 years but only very few

Re. 2:
The air velocity through a construction with dynamic insulation has a typical value of about 2 m/h. In an ordinary filter the typical velocity through the filter material is about 400 m/h which is a factor of 200 higher. If it takes half a year to fill an ordinary filter it will take significantly more time before the insulation have to be changed. There are lots of uncertainties in such a simple calculation but it gives an idea of how fast the insulation will be contaminated.

Re 3:
The author is aware of just a few 10 years old buildings with dynamic insulation in which the indoor air quality have been evaluated. There are not reported any mould growth or high concentration of endotoxin in the insulation.

Since there are uncertainties, and "better to be safe than sorry", we recommend to have a filter on the incoming air before it enters the insulation. This is a necessity where the insulation, not in a simple way, can be removed and replaced by a clean insulation if the insulation will cause problems before the building is ready to be condemned

CONCLUSIONS

The following conclusions can be drawn from the field experiments on four residential buildings:

- Dynamic insulation can give good indoor air quality and ventilation without draught in residential buildings.
- Dynamic insulation can reduce conduction heat loss from the construction to 0.
- It is important to choose a strategy on how to get the right air flow rate into the house without influence of the weather condition, the air tightness of the house and the users.
- The incoming air in house 3 and 4, after it has passed the insulation, contain only 7% and 8% of the number of particles in the outside air.
- The measurements do not indicate any mould growth in the insulation

ACKNOWLEDGEMENT

This work was funded by

- Research Council of Norway under the program "Product Development and Experimental Building"
- Bærum County
- Norwegian Building Research Institute.

The author would like to thank Ingunn Milford Johannessen and Odd Magne Solheim at the Norwegian Building Research Institute for their help in carrying out the measurements and for transferring the measured data into an understandable format.

REFERENCES

/1/ Anderlind, G. and Johansson, B.
Dynamic insulation, a theoretical analysis of thermal insulation through which a gas or fluid flows. D8:1983, Swedish Council for Building Research

/2/ Dalehaug, A.
Dynamic insulation in walls. Research report No. 53 1993, ISSN 0915-9215 Hokkaido prefectural cold region housing and urban research institute, Japan

/3/ Boman, C-A., Matsson, M.
Provhus med dynamisk isolering. Swedish Council for Building Research R142: 1981. (In Swedish)

/4/ Thorén, T.
Hallbyggnader med dynamisk isolering. Redovisning av utvecklingsläget. Swedish Council for Building Research, R66: 1986. (In Swedish)

/5/ Brunsell, Jørn T.
The Performance of Dynamic Insulation in Two Residential Buildings Proceedings from the 15th AIVC Conference, Buxton, UK, Sept. 1994

LIST OF SYMBOLS

A	Roof area	m^2
Q_a	Volume of air flow rate from attic to apartment	m^3/h
Q_t	Volume of total air flow rate through the apartment	m^3/h
T_i	Temperature inside	°C
T_o	Temperature outside	°C
T_r	Reference temperature	°C
U	Thermal permeance	$W/m^2{}^\circ C$
V	Volume of the apartment	m^3
c_a	Concentration of tracer gas in the attic	ppm
c_i	Concentration of tracer gas in the apartment	ppm
c_p	Specific heat capacity	J/kg°C
d	Thickness	m
n	ventilation rate	h^{-1}
n_{50}	ventilation rate at 50 Pa pressure difference	h^{-1}
q_d	Conduction heat flow	W/m^2
q_v	Convection heat flow	W/m^2
v	Air velocity	m/h
α_i	Surface film coefficient for heat transfer	$W/m^2{}^\circ C$
λ	Thermal conductivity	W/m°C
ρ	Density	kg/m^3