Settling and acceptable size of gaps in loose-fill thermal insulation in walls

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ABSTRACT: Settling in loose-fill insulation may occur due to bad workmanship, low density of the filling, and vibration e.g. from transport, from wind and from banging of doors and windows. It may cause increased heat loss, low surface temperatures and water vapour condensation. In order to assess the risk of settling full-size wooden walls with various insulation materials were subjected to vibration tests in **part A** of the project (i.e. transport over a selection of road and simulated vibrational load from wind, doors and windows). Except for perlite, the insulation materials showed no settling when filling procedures and densities conformed to the relevant standards. In a follow-up project (**part B**) the influence of settling on temperature and condensation is investigated at the moment. Gaps are implemented on purpose. Surface and internal temperature is monitored in a hot box by measurement and infrared photography. The results shall indicate which gaps are acceptable and provide an infrared method to assess the severeness of gaps without opening the wall .

1 INTRODUCTION

Possible settling of loose-fill insulation in walls would constitute a severe obstacle for the use of the insulation material in the building sector. Gaps within the insulation would lead to an increased local heat loss (which in itself is not acceptable) and possibly to low surface temperature. The later could cause water vapour condensation and lead to mould growth.

Settling of loose-fill insulation in walls may occur due to bad workmanship or low density of the filling. It may also occur due to vibration, e.g. during transportation of pre-fabricated walls or during the lifetime of the wall e.g. from wind and from banging of doors and windows. If the loose-fill insulation in a wall has gaps which need to be filled after the building is finished, the repair would only be possible by opening the wall, thus destroying part of the building and causing high costs and possibly liability claims against the wall manufacturer or the builder.

To reduce the risk of settling in walls a number of experiments were carried out on walls with market available loose-fill insulation materials [1]. The experiments represent the (vibrational) load which might lead to settling in real life building as opposed to already introduced settling tests during production and quality control of the insulation material itself which are more aimed at describing the basic material properties.

2 SETTLING TESTED PRODUCTS

2.1 Insulation materials tested

Following loose-fill insulation materials were included in the first part of the project:

- cellulose fibre, made from waste newspaper (2 manufacturers)
- wood fibre, made from soft wood (1 manufacturer)
- wood shavings, made from soft wood, with dimensions of up to 50mm x 25mm x 2mm (length x width x thickness) (1 manufacturer)
- expanded perlite (1 manufacturer)
- flax/polyester fibre sheets (80% flax fibres with 20% polyester fibres; the polyester fibres are used to stabilise the sheets) (1 manufacturer).
- glass wool sheets (1 product with fibre orientation parallel to wall surface; 1 product with fibre orientation perpendicular to wall surface) (1 manufacturer).

2.2 Properties of insulation materials tested

Loose-fill insulation materials are usually characterized by material tests which do not necessarily resemble the actual material properties in the wall (i.e. the density in the material test and in the wall differ substantially) [1,4]. This means that the figures derived are not to be transferred directly to the expected behaviour of the insulation material in a wall.

As a settling test loose-fill insulation material is filled into an open box of 0.1m³ volume ("open box test"). The settling ratio is determined by one of two procedures: either by dropping one side of the box 20 times on a hard surface over a certain height, or by mounting the box on a mechanical shaker which does a similar procedure automatically. In the test the maximum allowed density is much lower than requested for the application in walls so one should expect the settling factor to be much higher than in a wall. The average material properties of the products tested are presented in Table 1.

2.3 Element walls

The wooden wall elements had dimensions of 2.50m x 1.25m x 0.19m (height x length x thickness) with a 15mm OSB board on the inside and a 15mm DWD board on the outside surface. In most walls a wooden upright post would separate the inner space of the wall leaving two chambers of net dimensions 2.30m x 0.54m x 0.16m (height x length x thickness) for the insulation material. Two additional walls were supplied with insulation layer thicknesses of 220mm and 260mm resprectively. The walls were filled in an upright position in the institute by personnel trained and recognised by the respective insulation manufacturers. This ensured that the materials were applied in the same way they would have been handled in a real-life building. The filling procedure was supervised by institute staff.

The cellulose fibres and wood fibres were injected into the walls by means of pressurized air. The perlite insulation was manually filled into the wall. The flax/polyester fibre and glass wool sheets were put into place in the open wall and the inner OSB panel mounted afterwards. As an exemption the wood shavings walls were filled not in the institute but at the manufacturer. For the wood shavings the height of the insulation chambers was separated into three similar partitions by plywood panels mounted within in the chamber. This effectively reduces the pressure on the filling from its own weight thus preventing too much settling in the lower parts of the wall. The plywood partitions are required for wood shavings in the relevant technical approval.

3 SETTLING EXPERIMENTS

Full-size wooden pre-fabricated walls with various insulation materials were subjected to vibration tests [1] as first part of the project.

3.1 Flat-bed trailer transport

In the first test, a selection of filled walls were mounted on a flat-bed trailer and transported over a representative selection of roads (motorway and country lane) for approx. 350 km (see also E DIN 30787-2) [3].

3.2 Pendulum test

In the second set of tests the vibrational load from wind and from banging of doors and windows was simulated in a test rig developed for this project by means of a pendulum.

The pendulum consisted of a metal pipe with rectangular cross section filled with sand. The kinetic energy of the pendulum resembled that of a standard house entrance door with a weight of 60kg which hits the door frame at a speed of 0.5 m/s. This test condition is also used for durability tests of doors and hatches according to DIN EN 1191 [4]. The pendulum was pneumatically displaced in a movement parallel to the wall surface and hit the wall surface perpendicular with the area of contact having a height of 1.5m. A strip of cellular rubber between on the pendulum surface simulated the rubber damper within the door frame.

The test was automatically repeated 33.000 times corresponding to roughly 9 years of usage with 10 hits a day. The tests were carried out both on previously transported and on newly filled walls. A photograph of the test rig is given in Figure 1.

4 RESULTS ON SETTLING

After the experiments (flat-bed trailer transport and pendulum test) the walls were brought in a horizontal position and the OSB board on the inner wall surface removed. The density of the insulation material was measured separately for the lower, middle and upper third of the wall. At the same time the sellting of the insulation (if any) was recorded and photographed. With the perlite walls the upper wooden frame was removed first and the settlement of the material measured.

The density of the insulation material after the experiments is given in Table 2 whereas any settling is mentioned in the discussion in the following chapter.

5 DISCUSSION OF SETTLING

5.1 Cellulose fibres, manufacturer A

Manufacturer A took part in the project with a total of four walls (2x insulation thickness 160mm, 1x insulation thickness 220mm, 1x insulation thickness 260mm). The settling ratio in the open box test corresponded well to the maximum settlng ratio for the material. None of the walls showed any settling. The average density of the cellulose fibres in the walls tested was samewhat higher than the set density range stated in the technical approval.

Figure 1. Pendulum test rig with wooden wall.

5.2 *Cellulose fibres, manufacturer B*

Manufacturer B took part in the project with two walls (both insulation thickness 160mm). The settling ratio in the open box test corresponded well to the maximum settling ratio for the material. None of the walls showed any settling after the experiments. Again the density of the insulation layer was higher than the set range given in the technical approval.

5.3 *Wood fibres*

The manufacturer took part in the project with one wall which was subjected to the pendulum test. The settling ratio in the open box test stayed well below the allowed maximum. In the wall the wood fibres showed no settling. Figure 2 shows the opened wall after the experiments.

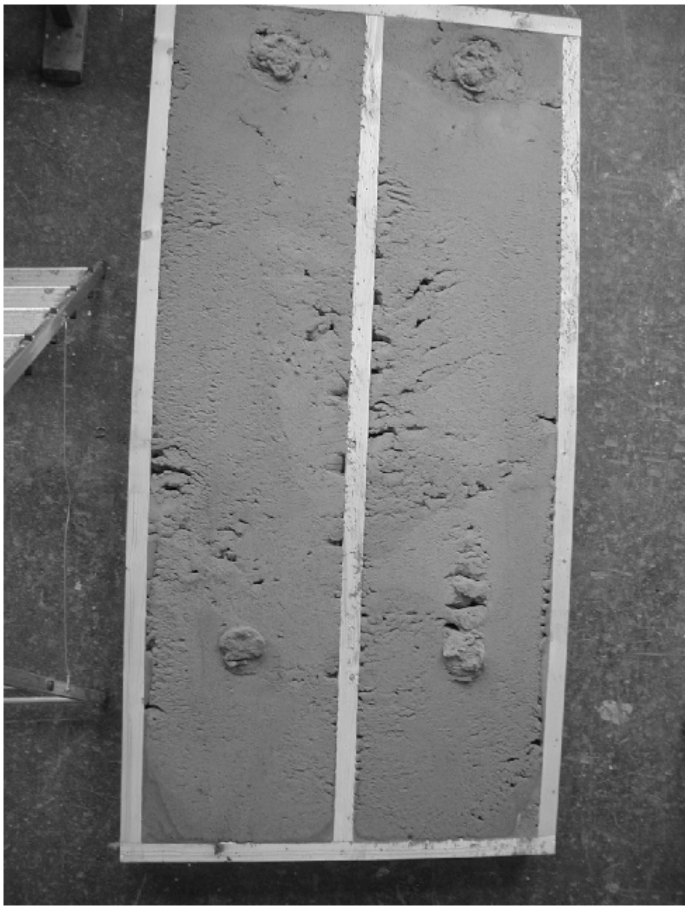

Figure 2. Opened wall with wood fibre insulation after tests.

5.4 *Wood shavings*

The two walls tested were filled and delivered to the institute by the manufacturer. In order to reduce the load on the insulation material in the lower part of the wall due to its own weight two plywood panels have to be used to separate the insulation chamber into three nearly equally sized compartments. Immediately below the panels and the upper wooden frame the material settled approximately 5mm. The density of the material was well within the limits set by the techical approval. Figure 3 shows the opened wall after the experiments.

5.5 *Expanded perlite*

In the process of manually filling the wall the wall had to be beaten several times on order to achieve an increase in density of 10% as demanded by the technical approval. The wall was subjected to the pendulum test. In both halves of the wall the material settled approximately 98mm due to density increase.

dry bulk density of the material was well within the range set by the technical approval.

Figure 3. Opened wall with wood shavings after tests.

5.6 Flax/polyester fibres

Two walls with flax/polyester fibre sheets took part in the project. In one side of the walls the sheets were squeezed in (the sheets were approximately 5 to 10mm wider than the compartment), in the other side they were additionally fixed with staples. None of the walls showed any settling.

5.7 Glass wool fibres

Two walls with glass wool fibre sheets took part in the project. One side of each wall was filled with the fibres oriented parallel to the wall surface, in the other side the fibres were oriented perpendicular to the wall surface. In both cases the sheets were somewhat wider or thicker respectively than the compartment and were squeezed in. None of the walls showed any settling.

6. CONCLUSIONS ON DANGER OF SETTLING

With insulation sheets (flax/polyester fibres; glass wool fibres) there is no danger of settling, as expected (nevertheless this was a question with a number of insulation manufacturers and fitters so it was decided to include some sheets in the study). Again no danger of settling exists for wood fibres; the very little gaps in Figure 2 are caused by the filling process and have no practical influence on the wall performance. The settling danger for cellulose fibres could not be assessed conclusively due to the high densities of the wall fillings. The open box test indicates a close relation between settling factor and density of cellulose fibres at low densities (which are not applicable for walls). Due to limited funding the cellulose fibre experiments could not be repeated. However within the set density range in walls there should be no or only very little settling. The settling of wood shavings should be limited by panels separating the insulation chamber into several compartments as demanded by the technical approval. The remaining settling is well within the allowed range and has no practical impact on wall performance. Expanded perlite showed some settling due to density increase.

PROJECT PART B: HYGROTHERMAL CONSEQUENCES OF GAPS

7. HYGROTHERMAL EXPERIMENTS

Wooden pre-fabricated walls with various insulation materials were tested in a double climate chamber under stationary temperature difference (+20°C front side, -15°C rear side; see Figure 4) in order to study the effect of gaps in the insulation on surface temperature and to assess the risk of water vapour condensation and mould growth [5]. The walls were on purpose equipped with various holes in the insulation layer to simulate gaps from settling and bad filling. The temperatures on the warm side wall surface and within the walls were monitored by means of thermocouples and with infrared photography.

In order to study the effect of gaps in the insulation combined with increased interior surface resistance (in corners, behind cupboards) in a number of tests the wall elements were equipped with additional panels simulating the adjacent wall, ceiling and floor, see Figure 4. In a number of experiments empty wall elements were placed immediately next to the inside surface of the walls under test to simulate cupboards.

Some more experiments are to follow with an additional inside insulation layer of 60mm thickness which acts as an installation layer for wiring and plumbing. With this type of construction the water vapour barrier is located on the wooden panel between the installation layer and the main insulation layer in the wall body. At spots where there is a gap in the insulation layer the water vapour barrier would lie on the cold side of the insulation. If the gap in the insulation is big enough this could give rise to interstitial condensation which would eventually damage the wall.

Figure 4: Top: 3 wall elements in double climate chamber (seen from warm side). Bottom: simulated corner (ceiling, wall, floor).

7.1 Wall elements

The walls had dimensions of 1.60m x 1.60m x 0.19m (width x height x thickness) with a 15mm OSB board on the inside and a 15mm DWD board on the outside surface. A wooden upright post separated the walls into two compartments of net dimensions 0.72m x 1.44m x 0.16m (width x height x thickness). The separation between the hot and cold side of the double climate chamber consisted of three wall elements so always 6 compartments were tested at a time.

7.2 Insulation materials tested

From the insulation materials covered in part A of the project the following materials were considered in part B:

- glass wool sheets (1 manufacturer) (because it is rather easy to cut out a portion of the insulation material leaving a clearly defined hole in the insulation);

- wood fibre made from soft wood (1 manufacturer); the walls were filled in the institute by the manufacturer. After testing in the double climate chamber the OSB board will be removed and the gaps within the insulation (from incomplete filling) recorded and tried to be linked to surface temperature differences during the test. Afterwards various holes will be cut into the insulation layer and the test repeated.

- wood shaving, made from soft wood (1 manufacturer). The walls will be filled by the manufacturer in the company and then transported to the institute. Small paper boxes in the wall or low filling density will be used to generate gaps in the insulation layer.

7.3 Gaps investigated

So far the influence of the following gaps in walls with glass wool insulation have been studied:

– round holes with diameters between 10mm and 180mm
– square holes with dimensions 10mm x 10mm to 180mm x 180mm
– horizontal gaps with width 510mm an heights between 10mm and 180mm
– vertical gaps with heights 25mm, 100mm, 500mm and widths between 10 and 120mm.

8. HYGROTHERMAL RESULTS

8.1 Documentation of surface temperature

Figure 5 gives an example of the experiment documentation with the size of gaps within the insulation layer and with the effects on surface temperature. The photograph at the top of the page shows the 6 compartments under test from the warm side before the experiment; the inside board is removed (for the experiment the inside board is replaced). The size of the gaps differs in all compartments: the horizontal gap at the top of the compartments and the round hole in the insulation in the bottom part of the wall get bigger from left to right; the vertical gap at the right edge of the compartments and the square hole get smaller from left to right.

Below the photographic presentation one can see the infrared photograph of the inside (warm side) surface temperature taken in equilibrium condition. The measured surface temperatures of course correspond to the actual air temperatures on both sides of the wall during the experiment (+20°C, -15°C).

However it would be possible to scale the colour range of an infrared photograph taken from another wall subjected to different air temperatures on either side in order to compare it with the colour distribution shown here for the test wall under test temperature conditions.

The table at the bottom of the page gives the dimensions and the lowest inside surface temperature for all 24 gaps covered by the individual test.

8.2 Inside surface temperature over gap area

Figure 6 gives plots of measured lowest warm side wall surface temperatures at various gaps in the insulation versus the size of these gaps. The range of dimensions for the gaps is given in section 7.3 above. The measurement data are denoted by discrete data points. Also given are the trend lines through the measurement points. It is still to be investigated whether the representing equations for the trend lines could be grouped into two groups (one for holes with similar height and width, i.e. round and quadratic holes; one group for the other gaps) and whether this has a physical meaning.

9. DISCUSSION AND ONGOING WORK

As one can see from Figure 5, even with rather big gaps in the insulation layer the inside wall surface temperature does not drop to below ca. 13°C. This would mean that under standard indoor climate no surface water vapour condensation due to gaps in the insulation needs to be feared as long as the gaps are not located in wall sections near corners or behind furniture, curtains etc. However the reduced surface temperature might lead to dark marks on plastered or white painted surfaces because more dust settles on surfaces with lower temperature. This effect does not harm the structure of the building but can be annoying for the people living there and is adverse to the image of wooden element houses. The effect has been observed in a number of buildings.

9.1 Current and future work within the project

However in corners between adjacent building components or behind furniture, curtains etc. the lower inside surface temperature could give rise to water vapour condensation on the wall surface. The surface temperature in such situations is currently being investigated in the project. Afterwards the effect of additional inside insulation layers (installation layer for wiring and plumbing) on the danger of interstitial condensation at gaps in the main insulation layer will be investigated.

The project is to be finished by the middle of August 2003. At that time it shall be possible from the experimental results to conclude which size of gap is acceptable in which circumstances and in which type of wall construction with respect to water vapour condensation. The documentation of the experiments (as shown in Figure 5) may also serve as a catalogue to assess the severeness of gaps by infrared photography without opening the wall in completed buildings.

10 SUMMARY

Part A: In order to assess the risk of settling due to vibration, full-size wooden walls with various insulation materials were subjected to different vibration tests representing the vibrational load acting on the wall during transport to the building site and during lifetime service. After the experiments the walls were opened, the density of the insulation material measured and any settling recorded.

Except for expanded perlite, the insulation materials showed no settling and can thus be considered "safe" in terms of settling. This requires the filling procedure and densities to conform to the relevant technical approvals. For both cellulose fibres tested the density in the walls was above the set density range.

In a follow-up project (Part B) the influence of gaps within the insulation on temperature on the wall surface and within the wall and on the risk of water vapour condensation is investigated at the moment. Gaps are implemented in the walls on purpose. Surface and internal temperature is monitored in a double climate chamber by measurement and infrared photography. The result indicate which gaps are acceptable. The project shall also provide a method to assess the presence of gaps and their severeness in existing buildings without opening the wall by comparing infrared photographs with those taken for known gaps in the test chamber. First results are given in this paper. The work shall be finished by August 2003.

REFERENCES

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[5] Schmitt, H. & Heinz, S. *Untersuchung der Auswirkung von Fehlstellen in der Dämmebene bei Holzständerwänden.* Diplomarbeit (BSc thesis), Fachhochschule Rosenheim, to be submitted August 2003.

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Table 1. Material data of the loose-fill insulation materials tested. “n.a.“ = no set value / not tested.

material	set bulk density for use in walls according to technical approval or standard kg/m³	set density for open box test kg/m³	measured density in open box test before settling (average) kg/m³	set settling factor for open box test according to technical approval or standard %	measured settling factor in open box test (average) (and span) %
cellulose fibres, manufacturer A	45-60	≤ 35	33	≤ 15	16 (14-18)
cellulose fibres, manufacturer B	35-55	≤ 35	32	≤ 15	15 (11-21)
wood fibre	30-60	≤ 35	39	≤ 15	5
expanded perlite	90 ± 20%	n.a.	96	≤ 10	10
wood shavings	50-90	n.a.	n.a.	n.a.	n.a.

Table 2. Density after experiments. “n.a.“ = not tested / not applicable.

material	set bulk density for use in walls according to technical approval or standard kg/m³	average density after experiments, left hand side of wall kg/m³	average density after experiments, right hand side of wall kg/m³	density after experiments, bottom/middle/top; left hand, right hand side kg/m³	remarks
cellulose fibres, manufacturer A	45-60	78	n.a.	83/76/77	insulation thickness 160mm
“	“	76	80	81/72/75 82/75/84	insulation thickness 220mm
“	“	76	79	78/82/74 83/76/79	insulation thickness 260mm
cellulose fibres, manufacturer B	35-55	62	67	56/66/64 59/77/64	no lorry transport
“	“	70	n.a.	71/71/68	---
wood fibre	30-60	46	47	38/44/55 39/47/56	no lorry transport
wood shavings	50-90	69	74	71/68/68 74/75/72	---
expanded perlite	90 ± 20%	104	103	104/107/101 105/105/98	no lorry transport
flax/polyester fibres	n.a.	34	36	32/34/35 37/35/36	no lorry transport
“	“	37	36	37/35/37 36/35/38	---
glass wool fibres	n.a.	16	n.a.	n.a.	fibres parallel to wall surface
“	“	21	21	21	fibres perpendicular to wall surface

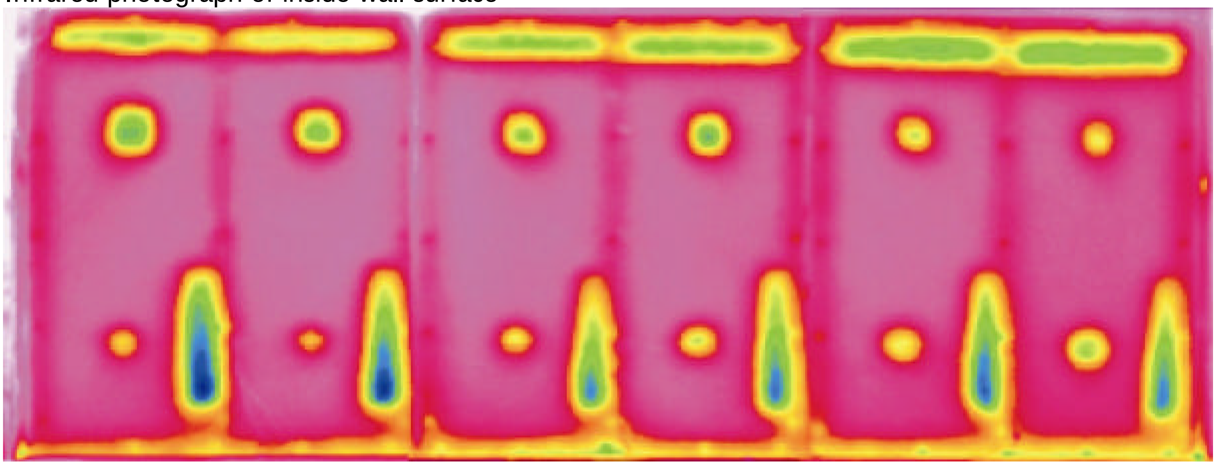
Experiment documentation

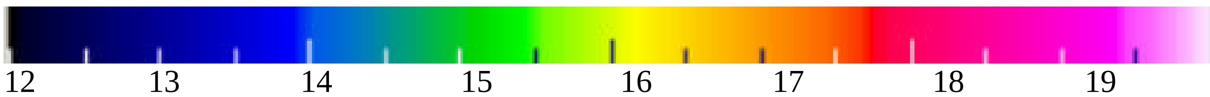
Experiment: *Gaps 6-12 cm*

Temperature: *inside (front) +20 °C, outside (rear) -15 °C*

Gaps – Photograph (wall board removed)

Infrared photograph of inside wall surface





gap	dimensions			lowest surface temperature	gap	dimensions			lowest surface temperature
	width mm	height mm	area cm²	° C		width mm	height mm	area cm²	° C
horizontal (from left to right)	510	70	357	15,3	quadratic (from left to right)	120	120	144	14,7
	510	80	408	15,7		110	110	121	15
	510	90	459	15,6		100	100	100	15,9
	510	100	510	15,8		90	90	81	15,3
	510	110	561	15,4		80	80	64	16,3
	510	120	612	15,4		70	70	49	16,5
vertical (from left to right	90	500	450	13,1	round (from left to right)	70	70	49	16,4
	85	500	425	13,2		80	80	64	16,6
	80	500	400	14,2		90	90	81	16,4
	75	500	375	13,9		100	100	100	16,2
	70	500	350	13,9		110	110	121	16,5
	65	500	325	14,2		120	120	144	15,9

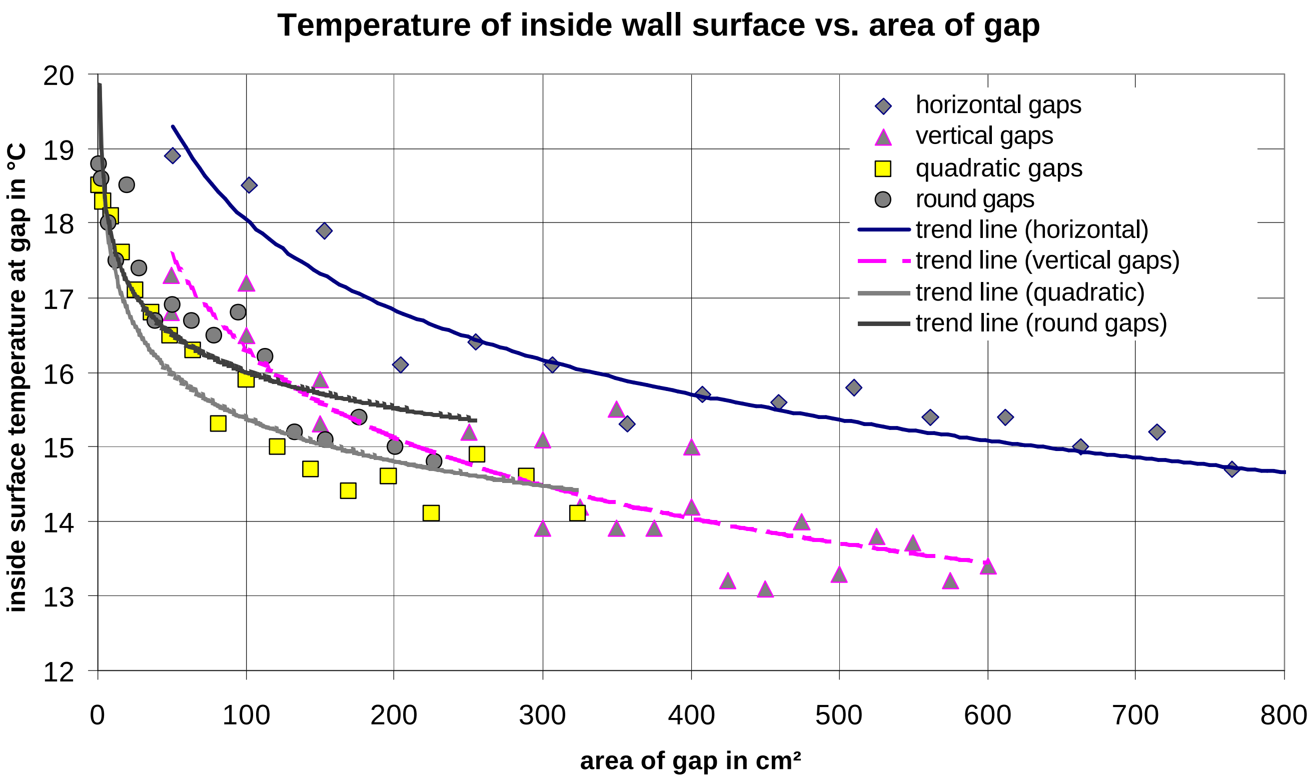


Figure 6: Minimum temperature of inside wall surface on gap versus area of that gap.