

# **Comfort from innovative floor heating system with high sound insulation**

Functionality and technical background  
Advantages and benefits

**Author:**

Dr.-Ing. Klemens WESOLOWSKI  
Technical Director

METAWELL GmbH  
Schleifmühlweg 31  
86633 Neuburg a. d. Donau  
Germany

Tel. +49 (0)8431/6715-0  
[info@metawell.com](mailto:info@metawell.com)  
<https://www.metawell.com>

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## 1. Introduction

Comfort in modern rail vehicles contributes significantly to passenger acceptance of trains as a means of transport. The following is an innovative floor heating system for electrically powered vehicles for passenger transport, which, besides increasing comfort, as is especially required for vehicles for long and medium distances, fulfils further requirements such as lightweight construction, sound insulation and low LCC costs through the efficient integration of components and function.

## 2. Advantage of lightweight, electric floor heating

The various basic requirements for heating systems of passenger rail vehicles for regional and long-distance trains are, in part, complementary and closely interlinked:

- High level of comfort
- Low costs
- Low weight

The very general requirement of "high comfort" leads to the specification of comfortable additional heating, which is accompanied by very even heat distribution without any air drafts. Large-area heating with very even heat distribution on the surface makes it possible to keep the heating output per area relatively low, thus allowing a small difference between the ambient temperature and the surface temperature of the heater, which increases comfort. Therefore, from a "cost" perspective, it also makes sense to use existing large areas such as floors, walls or ceilings as surfaces for heaters.

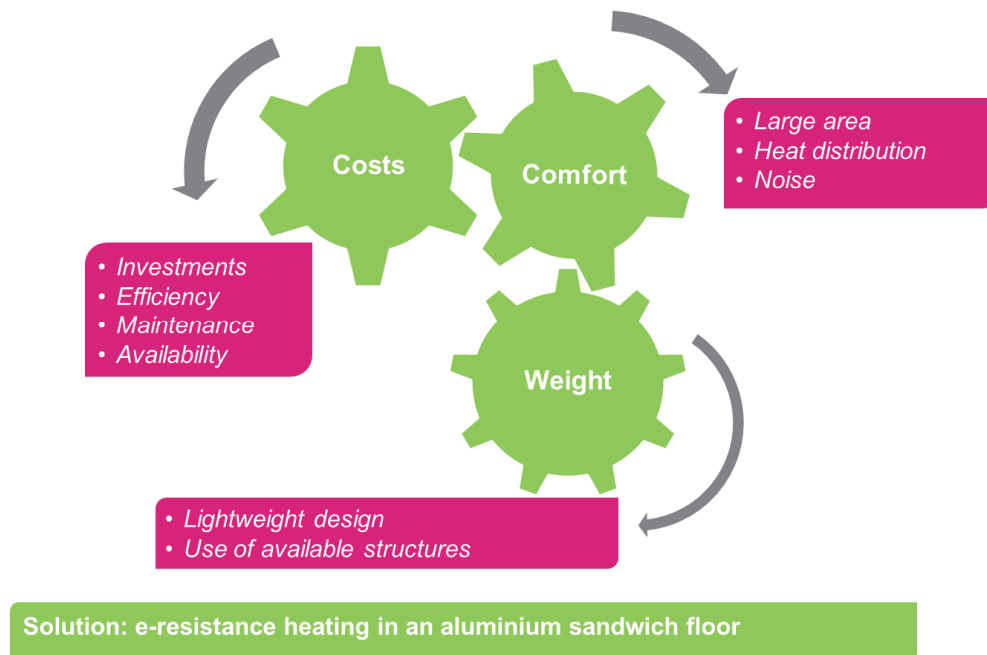
The floor particularly lends itself well as a heating element because the efficiency of natural convection (the heat rises), in addition to radiation from all large areas, is best at the bottom. This removes the need for additional units for transporting heat (blowers), which also has a positive effect on maintenance and service (LCC costs). Another advantage of floor heating is accelerated drying of the floor covering (reducing the risk of slipping) in humid and cold seasons. To increase the heating's efficiency, the floor material should have very good heat conduction.

In electrically powered vehicles, the primary energy on the vehicle is electric power, so an electric heater is the most effective energetically in this case. When using ohmic resistance heating, 100% of the energy loss at the resistor is converted into heat. If this heat can be transmitted to the surrounding structure, as is the case with floor material with good heat conduction, a very effective heating system can be obtained. Another advantage of pure ohmic resistance heating is the electro-magnetic compatibility, so no additional EMC protection measures (e.g. installation of a shield) are needed.

The general "low weight" requirement is often associated with costs. However, if existing structures are used as a heating surface, only little additional weight is required for the actual heating element. This is also why electric floor heating is lends itself particularly well as additional heating. The requirement of good heat conduction for the floor material, taking "low weight" into account, can be perfectly achieved by using an aluminium lightweight floor, which is designed for further weight optimisation in sandwich construction.

Thus, the ideal comfort solution for an auxiliary heating system for electrically powered vehicles for passenger transport is an aluminium sandwich floor with integrated electrical resistance heating, see Figure 2.1.

Figure 2.1: **Advantages of aluminium sandwich floor resistance heating**



### 3. Requirements of the aluminium sandwich floor system

There are various technical requirements for floor panels that must be observed, regardless of the heating function. In the case of floor systems with heating, these must also be protected against mechanical damage and other environmental influences, where applicable.

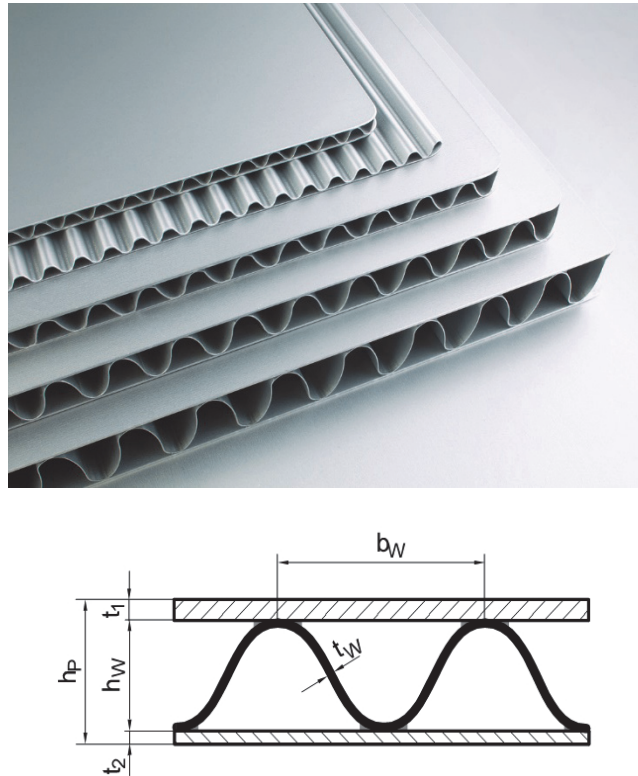
- |            |                   |                                                                                               |
|------------|-------------------|-----------------------------------------------------------------------------------------------|
| - Statics: | Bending rigidity: | Low deflection with large support distances                                                   |
|            | Area loads        | 350 to 770 kg/m <sup>2</sup> without permanent deformation,<br>No creep at long, static loads |
|            | Point loads:      | High loads on a very small area due to high heels<br>or suitcase wheels                       |

The static requirements also apply under permanent temperature load caused by the heating system. Aluminium sandwich panels can provide the required statics if there is adequate adhesion and an appropriate core structure - even when they are lightweight.

- |       |                          |                                                                                                                                   |
|-------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| - LCC | Durability of the floor: | Lifetime (> 30 years)                                                                                                             |
|       | Corrosion resistance:    | Use of corrosion-resistant material                                                                                               |
|       | Durability:              | Constant load changes especially in the boarding area                                                                             |
|       | Refurbishment:           | Sufficient strength against destruction of the floor<br>panel and the heating system while the floor covering<br>is being changed |

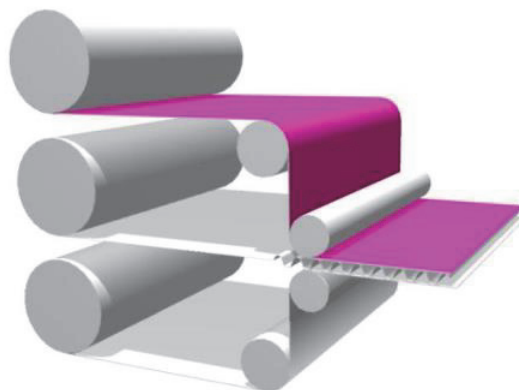
Because of its special construction with a sinusoidal core material (Figure 3.1), the Metawell® aluminium sandwich panel is particularly suitable as a load-bearing floor panel with a very long lifetime. The harmonic, almost notch-free connection of the core material to the cover sheets provides a high fatigue strength.

Figure 3.1: **Basic structure of the Metawell® aluminium sandwich panel**



The Metawell® panel is produced in a continuous production flow (Figure 3.2) in which two aluminium cover layers are glued to a sine wave-converted core material certified according to DIN 6701-2 (class A1) to form a "continuous panel", which is subsequently cut to length specific to the customer/project. The continuous flow and the sheet thicknesses allow for the use of particularly corrosion-protected aluminium strips, which are provided during the coil coating process [1] with a corrosion protection primer, which ensures a permanent bond. High-strength, seawater-resistant aluminium alloys [2] (EN AW-5754 H48 / EN AW-5182 H48 [3]) of the inserted sheets provide a high level of corrosion resistance even at bare spots and cut edges.

Figure 3.2: **Principle of the continuous production flow of Metawell® panel**



## 4. Function and technical details of the heating system

Due to their electro-magnetic compatibility, electrical resistance heaters are particularly suitable as heating elements for the good heat-conducting aluminium sandwich floor panels. For floor heating, there are generally three resistance heating systems, and the advantages and disadvantages of these are briefly presented.

### 4.1 Choice of heating element

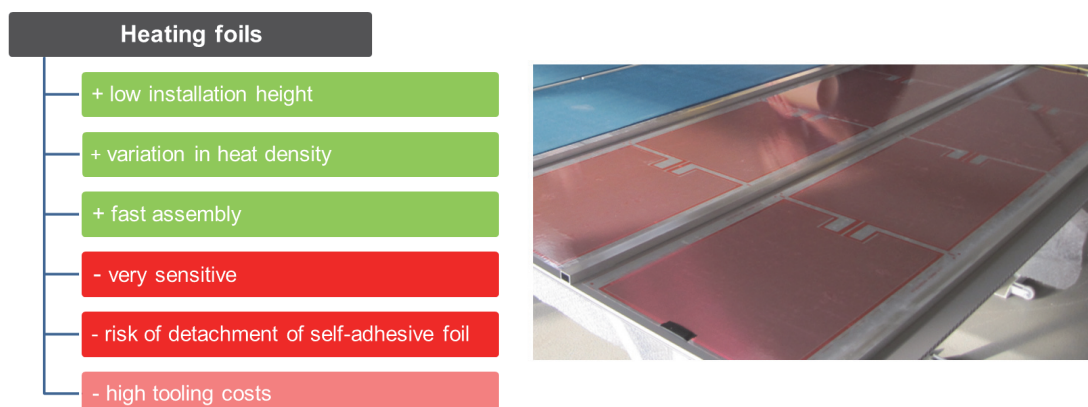
#### 4.1.1 Heating foils

Heating foils is one way of heating the floor panels. The resistor material is applied to a thin carrier material (often thin plastic foils) in a very thin layer. Due to the arrangement of the resistance loops, the heating density can be varied relatively freely with the tool design. However, depending on the method, a variance of the floor panel size and geometry requires many tools and can, therefore, cause high project-related tooling costs.

The heating foils are often attached in a self-adhesive manner below the aluminium sandwich panel. This has the advantage of quick installation and low construction height. The disadvantage is low protection against damage and the risk of the self-adhesive foil detaching over its lifetime, especially in the area of the connections. In addition, supports below the panel, which locally change the heat dissipation of the heating foils and also lead to pressure load, trigger "hotspots", which can lead to destruction of the heating circuit. Hot spots can also be caused by local detachment of the foil from the carrier panel.

Alternatively, heating foils can also be applied between the top cover sheet and the core material of the aluminium sandwich. In such cases, they are used as static-bearing components, which need to permanently transfer the shear forces from the cover sheet to the core. When a floor covering is being changed, the strength in this design, compared with peeling off the top cover sheet, is also determined by the internal strength of the heating foil.

Figure 4.1: Heating foils: Advantages and disadvantages

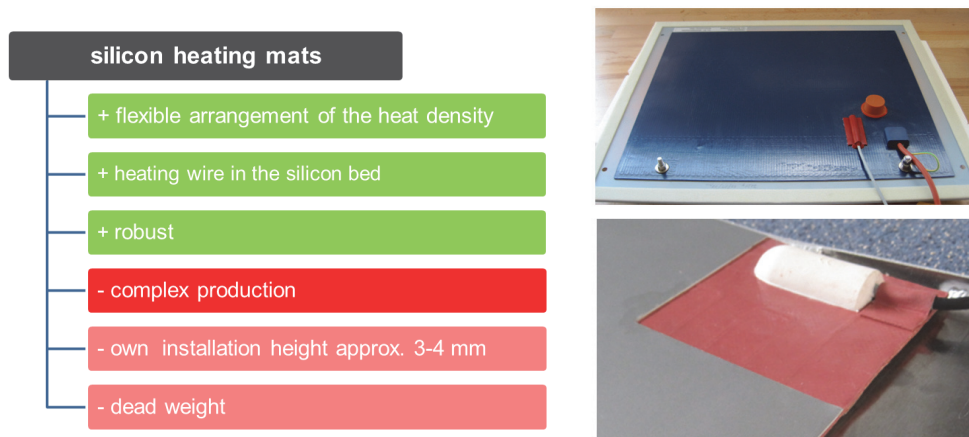


#### 4.1.2 Silicon heating mats

Another variant of the heating system application below the floor panel is application of a resistance heating wire in a silicone mat. The resistance wire is laid individually to the required power density on the first silicone layer and then vulcanised with the second layer. This gives a very high degree of flexibility without the need for producing new tools. However, establishing this with the vulcanisation process is quite expensive (costs).

The silicon heating mats are usually attached in a self-adhesive manner below the aluminium sandwich panel. Again, the quick assembly is advantageous with the slightly higher material thickness of the silicone mat. Due to the relatively high weight, overhead applications have a risk of detaching over their lifetime if there is no additional mechanical fixation. This risk can be reduced by additional mechanical fixings (integration of attachment points in the vulcanisation process). The relatively high weight of the heating mats, and the high level of elasticity of their silicon, is associated with an improvement in sound insulation as a positive side effect. With silicon mats, the danger of the hotspot is much lower than with heating foils.

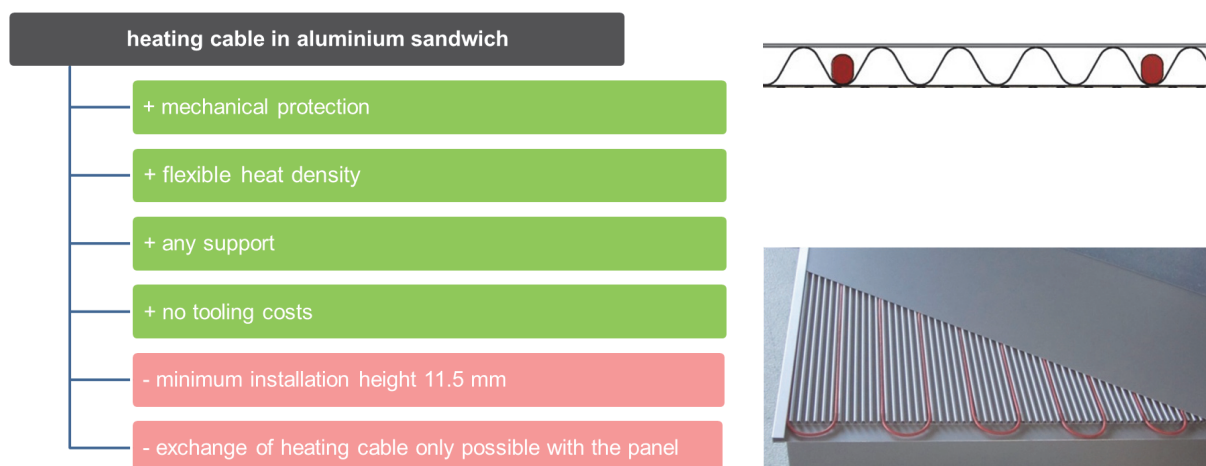
Figure 4.2: **Silicon heating mats: Advantages and disadvantages**



#### 4.1.3 Resistance heating cable integrated into the Metawell® sandwich panel

In addition to heating foils and silicone heating mats, the Metawell® sandwich panel enables the use of a heating cable that is fed through the corrugated ducts. With a corresponding structure and geometric adaptation of the cable to the open, corrugated cross-section, very good heat transfer is achieved via the guided contact between the heating cable and the corrugated duct, which is also permanently maintained.

Figure 4.3: **Integrated heating cable: Advantages and disadvantages**



Key advantages of this design include perfect protection of the heating cable from the surrounding cover plates, as well as a high level of flexibility in the power density through varying the distance of the occupied corrugated duct. Tool costs are not required. Placing the sandwich panel on the



substructure can be completely independent of the heater position, since the actual heating element is protected by the lower cover sheet. Likewise, there is no risk of the heating element detaching from the floor panel due to gravity, since the heating cable is mechanically fixed by the corrugated duct.

The heating wire itself is protected against any possible sharp aluminium edges by an elastic protective layer and an additional stainless-steel braid, which can be simultaneously used for grounding. This results in a minimum diameter of the heating cable, which, in turn, requires a minimum sandwich panel installation height of 11.5 mm. This could possibly be a disadvantage when there is very little space available.

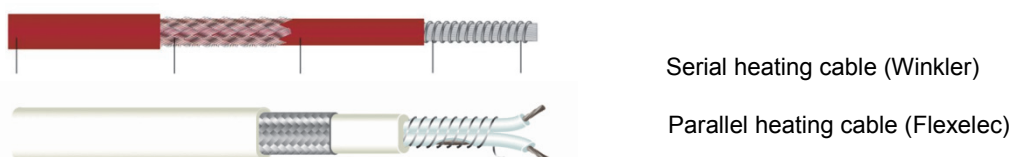
Another possible disadvantage is that the entire floor panel would need to be replaced if the heating resistor failed. Since it is also necessary to install and remove a floor panel, including disassembly of partial interior fittings components, and the change the floor covering when a heating foil or silicone heating mat fails, this disadvantage quickly becomes relative when considering the cost of material compared to the time for assembly and downtime, especially given that the probability of the mechanically well-protected heating cable failing is lower than a heating foil doing so.

Following internal evaluation of all advantages and disadvantages, investment costs, LCC and RAMS (risk of malfunction), Metawell opted for the solution with a heating cable integrated in the sandwich panel. If the installation space does not allow for integration of a heating cable, other heating systems are fixed under the sandwich panel.

### Structure of the heating cable

The basic structure of the heating cable for integration into the Metawell® panel consists of a resistance heating wire, which is wound spirally around a tensile-resistant carrier material. This winding shape generally rules out any axial tensile stress of the actual heating element. The heating wire is surrounded by an insulation layer (silicone for reasons of fire protection) and it has a metallic shielding above it (stainless steel to avoid corrosion). On the one hand, this metallic shield protects the heating conductor against mechanical damage, while on the other hand, it can be directly used for grounding directly on the heating element. In the case of silicone mats and heating foils, in the event of damage, grounding would only be possible via the floor panel. Thus, the integrated heating cable has an additional safety level. There is usually another silicone protective layer around the shield.

Figure 4.4: **Structure of the resistance heating cable with spiral winding**



The advantage of the serial heating cable is the smaller outer diameter, which thus allows an overall lower installation height of the floor heating. With the serial heating cable, the minimum installation height of the heated floor panel is 11.5 mm. A disadvantage is the lower flexibility of heat output and length, since a separate cable is needed for each electrical total output of the heating cable.

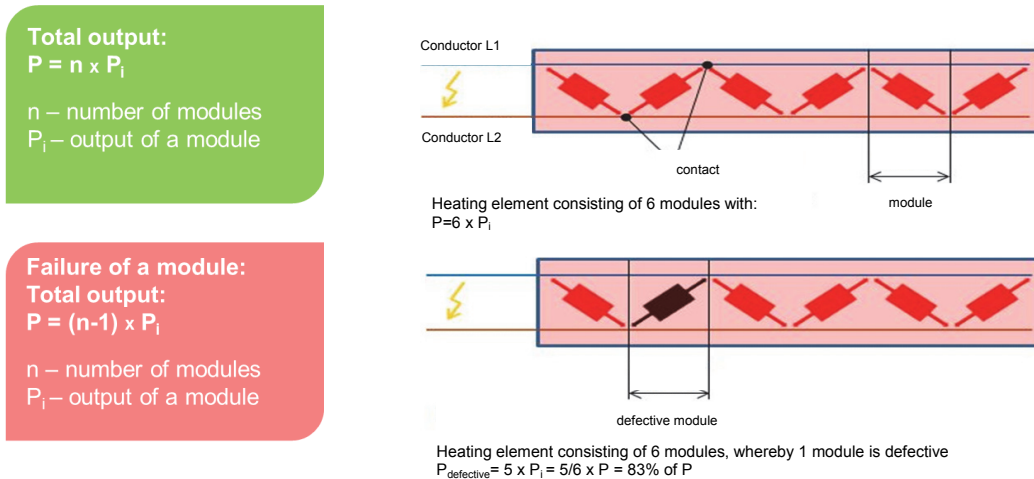
The high level of flexibility is a key advantage of the parallel heating cable. Here, the tension-resistant carrier consists of two stronger strands, to which the heating wire is connected at regular intervals. This creates parallel, identical resistors. The section between two contact points is called a "module". The total electrical power of the heating cable equals the sum of the individual module outputs. The heating cable can be cut to length from the roll to the required total output (with a maximum variance of +/- half the module output). The disadvantage is the larger cable cross-section, which requires a minimum installation height of 15 mm for the floor panel.

Another advantage of the parallel heating cable is the built-in redundancy for the resistance wire, see Figure 4.5. Should a resistance wire burn or break, the adjacent parallel resistors will not be affected. The overall output of the heating cable is only reduced by the output of a module. Due to the good



heat conduction of the aluminium sandwich panel, the failure of a module would have practically no influence on comfort.

Figure 4.5: **Redundancy for the heat resistance in the parallel heating cable**

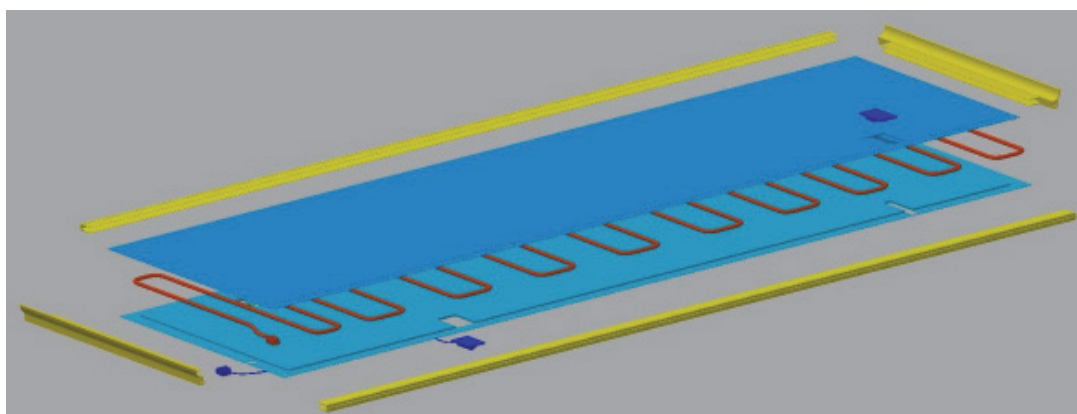


## 4.2 System solution of the heated floor panel from Metawell

### 4.2.1 Structure and technical parameters

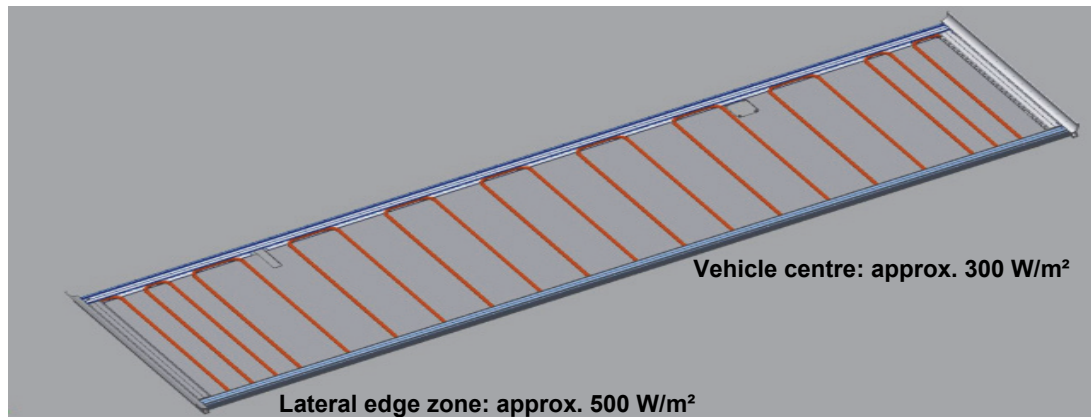
The basic structure of a heated Metawell<sup>®</sup> aluminium sandwich floor panel is virtually indistinguishable from an unheated one. This makes it possible to offer the **heating as an option** or to heat certain areas only when construction is otherwise uniform. The floor panel is usually edged on all sides of profiles, whereby the profiles can be used as a lateral edge termination to the side wall or for connection to the neighbouring panel (corresponding profile sections are available or can be produced specific to a project). If the panel is to be heated, the heating cable is drawn into the corrugated ducts at the desired power density during the manufacturing process before the profiles are glued (Figure 4.6 and 4.7.).

Figure 4.6: **Functional principle of the heated Metawell<sup>®</sup> floor panel**



Operating voltage: 100 to 400 volts AC or DC  
 Heating output: 150 to 600 W/m<sup>2</sup>

Figure 4.7: **Local adjustment of the heating power density**



The length of the heating cable is determined by the required total power and is usually limited by the maximum permissible current consumption of the connector, the supply line or the control unit, and by line losses in the strands of the heating cable.

At a maximum permissible current of 8 amps, for example, the output at 230 volts is a maximum of 1,840 watts. The usual heating output of floor heating is around 350 watts per square metre, so, under the conditions mentioned, there is a maximum panel size of approx. 5 square metres for a cable connection. Larger panel dimensions can be achieved by further cable connections. In addition to the electrical limitation of the maximum panel size, there are other parameters - such as maximum panel weight (occupational safety) and handling during installation (since the panel needs to be placed in the vehicle!) - that also play a crucial role. The largest floor panels that Metawell has ever built in one piece are over 40 m<sup>2</sup> in size, and the smallest is less than 1 m<sup>2</sup>.

The difference in temperature between the ambient air and the floor surface depends not only on the area coverage (W/m<sup>2</sup>), but also on the floor covering, the insulation under the panel and the dissipation of heat to other assemblies. As a rough guideline, a temperature difference of about 30 K at 350 W/m<sup>2</sup> can be used for a smooth surface.

#### 4.2.2 Temperature detection and control

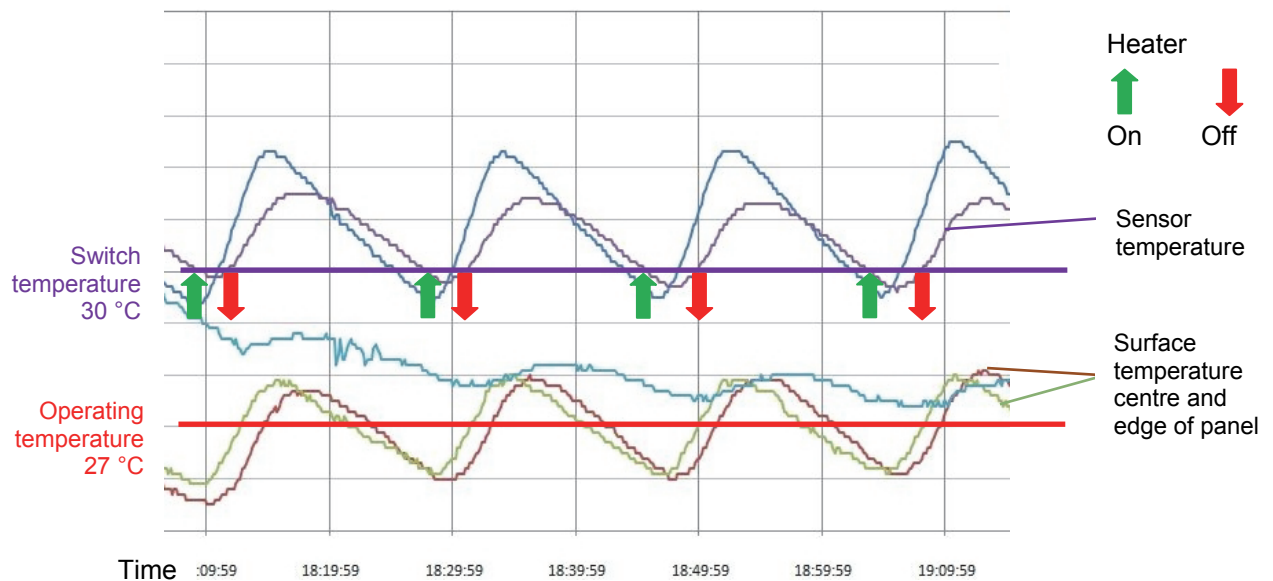
The temperature can be detected by sensors, which are designed as NTC or PTC resistance thermometers. Depending on the position of the sensor - near the surface or on the underside of the panel (above the insulation), the sensor will show a more or less significant difference to the surface of the floor covering. The temperature signal of the sensor can be used to control the floor heating if this difference is taken into account accordingly.

The maximum surface temperature of the floor heating in the comfort zone is generally between 27 and 32 °C (comfort zone = operating temperature). A possible control mode would be to switch off the heater when the operating temperature is reached, and to switch it on again after 1 minute (full power on - full power on - off ....)

Due to the specific heat capacity/inertia, the temperature will always overshoot, so that the surface temperature will continue to increase after switching off and may still be above the operating temperature after 1 minute. Therefore, a switching temperature (measurement comes from the sensor) should be used for the control, which is chosen because of the overshoot so that the maximum operating temperature is exceeded only slightly under consideration of the inertia. If this switching temperature is reached in the warm-up phase, the heating is switched off. At fixed time intervals (e.g. every minute), the sensor temperature is used to check whether there is a shortfall in the switching temperature. If there is a shortfall in the temperature, the heating is switched on again until the switching temperature is reached again. The hysteresis then starts again.

The example measurement in Figure 4.8 shows such a switching hysteresis, using the example of an operating temperature of 27 °C at the surface. The sensor temperature is used as a measuring signal for switching the heating on and off. The switching temperature was determined at 30 °C at the sensor. If the sensor temperature falls below 30 °C, the heating is switched on until the sensor reports 30 °C again. The heating is then switched off again. Although, in this measurement series, the heating remained switched off for more than 15 minutes due to the inertia, the surface temperature at the two measuring points only fluctuates by 27 °C +/- 1 K.

Figure 4.8: **Example measurement with switching hysteresis**



Of course, another type of control can also be selected in addition to the simple on - off control.

### 4.2.3 Safety circuit

In addition to the control system, a customer-specific safety system is usually required, which ensures that a maximum permissible surface temperature is not exceeded if the control fails. This is often solved by bi-metal switches (limiters). Here, a distinction should be made between bi-metal switches that are positioned in the heating circuit and those that are integrated in a control circuit.

#### Bi-metal switch in the heating circuit

If the bi-metal switch is installed in the heating circuit, each heating circuit must be equipped with a bi-metal switch for safety monitoring. The current that flows through the bi-metal switch is the same high current that flows through the heating circuit. There is no need for an additional contactor in the control cabinet. Thus, because of availability and durability, the bi-metal switch may be the power-limiting component, and the maximum output of the overall system may need to be further reduced compared to the parameters mentioned in 4.2.1.

With alternating voltage, a possible arc is quickly interrupted due to the periodic zero crossing of the voltage in the switching case of the bi-metal switch. With DC, it could be that the arc cannot be interrupted, and the switching contact would be destroyed. Therefore, bi-metal DC switches are only available in the low voltage range. Thus, it is not possible to use bi-metal switches in the heating circuit in high-power DC heating systems.

## Bi-metal switch in the control circuit

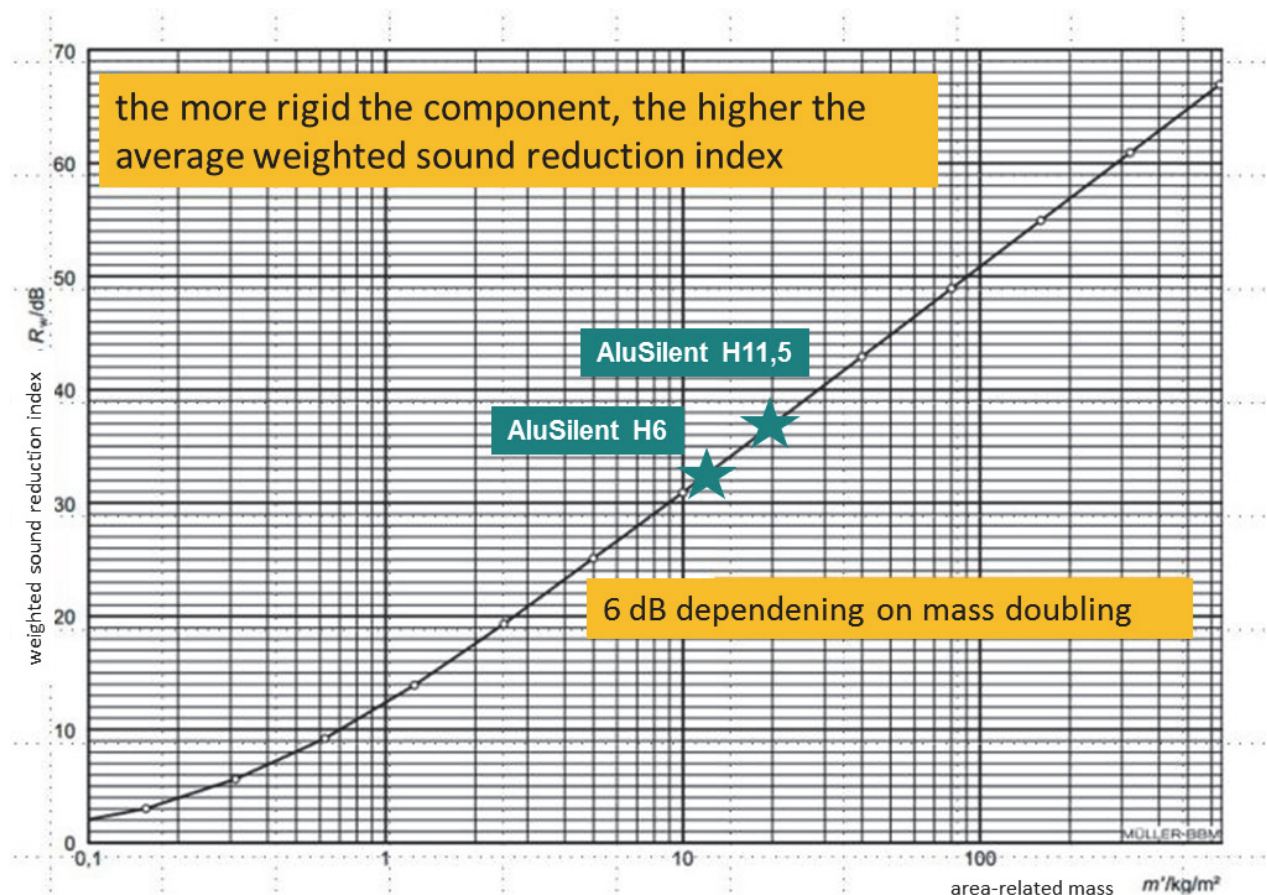
An additional contactor is needed when using a bi-metal switch in the control circuit. The main advantage is the independence of the bi-metal switch from the currents and voltages of the heating circuit (thus suitable for AC and DC heating systems), and also that, with a bi-metal switch, several hot plates can be monitored together when they are supplied together. If, in the event of a common supply, a panel without a bi-metal switch becomes too warm due to a faulty controller, the other panels which are supplied together with it also become too warm and the switch of another panel responds, and the contactor interrupts the circuit.

Since the control voltage is usually in the low-voltage range (e.g. 24 volts), the costs for such a bi-metal switch are lower than those for one inside the heating circuit with high voltage (IP protection).

## 5. Additional function - sound insulation

The customer requirements "sound insulation" and "lightweight construction" are unfortunately not easy to reconcile due to the physics. Mass is mainly required for sound insulation. Figure 5.1 shows the ideal case of the pure law of mass. Accordingly, at a weight of 10 kg/m<sup>2</sup>, an average weighted sound reduction index [4] of  $R_w = 31$  dB can be achieved at best.

Figure 5.1: Pure law of mass of physics



Source [5]: Müller-BBM GmbH Robert-Kochstr. 11 82152 Planegg

To approach the theoretically best possible values for the weighted sound reduction index, it should ideally correspond to a heavy membrane: heavy - and no stiffness!

However, a floor panel should be as stiff as possible to minimise the deflection at high support intervals and high surface load. Therefore, even with a lot of mass, the sound insulation of a rigid floor



panel can actually not approach the theoretically possible weighted sound reduction index without special measures. By way of example, two solid aluminium plates are named, whose determined, evaluated sound reduction index  $R_w$  is compared with the pure law of mass (Figure 5.1):

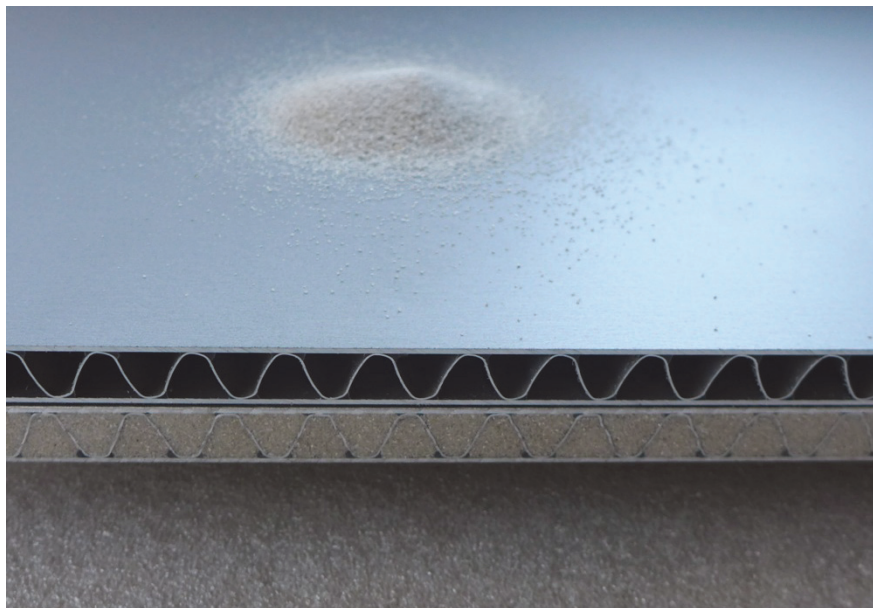
Alu panel	Weight	Sound reduction index Law of mass	determined sound reduction index [6]
6 mm	16.2 kg/m <sup>2</sup>	$R_w = 35$ dB	$R_w = 31$ dB
8 mm	21.6 kg/m <sup>2</sup>	$R_w = 37$ dB	$R_w = 31$ dB

Both panels are well below the values of the pure law of mass. Although the 8 mm panel is significantly heavier than the 6 mm panel, the additional mass is not noticeable due to the considerable increase in rigidity (the bending rigidity goes with the 3rd power of height:  $8^3 / 6^3 > \text{factor } 3000$ )!

However, mass usually also means a higher heat capacity and thus greater inertia during heating or cooling.

However, to get the best possible sound insulation for rigid floor panels, Metawell has combined its lightweight aluminium sandwich panels with a heavy material with no inherent rigidity. In a special process, special fracture sand is filled and compacted into the corrugation channels of the Metawell® panels. The open edges are then sealed with a sealant.

Figure 5.2: **Structure of the sound insulation panel "Metawell® Alu-Silent"**



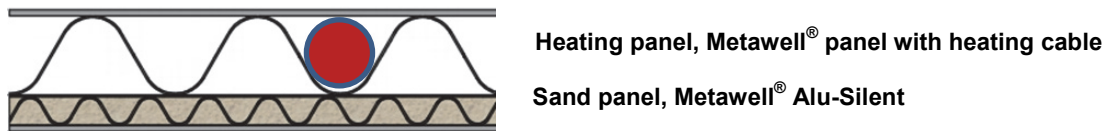
This clever combination of materials results in a rigid sandwich panel, whose sound insulation properties lie on the line curve of pure law of mass. With this surface weight, more sound insulation is physically not possible.

In Figure 5.1, two types of sand-filled panel have been entered as examples in the diagram: Metawell® Alu-Silent H6 and Metawell® Alu-Silent H11.5 (sandwich panels with a total thickness of 6 mm and 11.5 mm, respectively).

Another advantage of Metawell® Alu-Silent panels is that they can be optionally equipped with soundproofing. So, for certain applications, it may be useful to fill the same floor panel with sand above the bogie area, for example, for sound insulation and to heat the boarding area. It is not possible to fill sand and place the heating cable in the same panel section.

If both heating and sound insulation are required in areas, it is possible to combine a heating panel with a sand panel.

Figure 5.3: **Combination of a Metawell® heating panel with Metawell® Alu-Silent**



In a specific project, a weighted sound reduction index of  $R_w = 36$  was required for the heated floor. According to the pure law of mass, this requires a minimum weight of  $18 \text{ kg/m}^2$ . By combining the heating panel and Metawell® Alu-Silent, the requirement could be met with a total thickness of 22 mm and a surface weight of  $20 \text{ kg/m}^2$ . To be able to use the substructure and the overall concept for the complete vehicle, for reasons of weight, only the floor panels which are located in areas with high sound requirements (about 2/3 of the floor) were filled with sand.

## 6. References

Before the Metawell heated floor system was introduced to the market (Innotrans 2010), extensive investigations (such as fire tests, vibration tests, climatic chamber tests, overload tests, etc.) were successfully completed.

The first series application was introduced in 2011 with the heating of the cab floor of the Bombardier Traxx locomotives. A serial heating cable with a safety circuit in the heating circuit is used. Meanwhile, all locomotives of the Traxx family have been equipped with it.

In regional transport, since 2012, the railcars "Regio Panter" from Škoda Transportation have been equipped in the boarding area with an integrated serial heating cable in the Metawell® panel. The floor in the boarding area undergoes particularly frequent load changes and significant corrosion by aggressive media.

The first major project in high-class long-distance transport is the equipping of the entire floor of the EC 250 Giruno with a heated floor, mostly with additional sound insulation.

Figure 6.1: **EC 250 Giruno, Stadler Rail AG [7]**



About 2/3 of all heating panels in the passenger area, as well as all heating panels in the driver's cab, are also filled with sand to improve sound insulation. The heating cable in the passenger area and in the driver's cab is designed as a parallel heating cable. The safety circuit is provided by bi-metal

switching blocks with 2 safety levels (45 and 60 °C), which are connected in a low-voltage control circuit. Thus, with a bi-metal switching block, several heating panels can be monitored.

Figure 6.2: **EC 250 Giruno, Stadler Rail AG, passenger area and parallel heating cable**



In the boarding area, the ramps made of solid sheet are equipped with silicone mat heating for reasons of space. The floor panels between the boarding ramps are equipped as Metawell® panels with integrated serial heating cables. In total, every EC 250 Giruno has more than 2.5 km of heating cables installed in Metawell® panels.

## 7. Summary

An additional electric heating, designed as a heated aluminium sandwich floor panel, offers considerable advantages in terms of comfort, cost and weight in modern regional and long-distance trains. By integrating a resistance heating cable in the corrugated ducts of the Metawell® floor panel, further system advantages can be generated in combination with a high sound insulation. The functioning of the systems is explained and stored with technical data.



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