# An innovative thermally activated light-weight steel deck system – numerical investigations and practical tests

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## SUMMARY

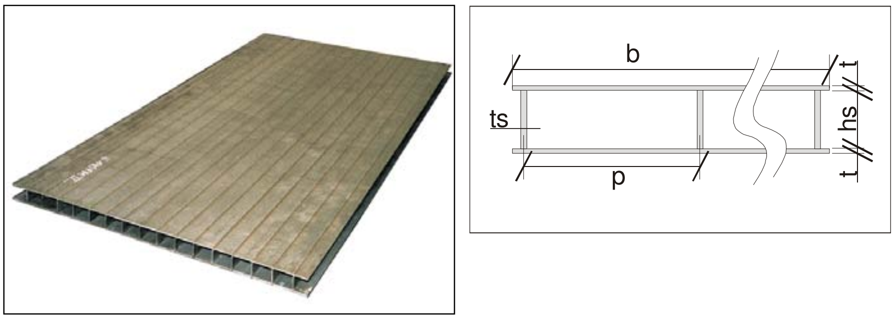
A prefabricated deck system made of laser-welded steel sandwich panels (LSP), up to now only used for decks in shipbuilding, shall be improved for the use in buildings. Beneath other items like fire safety, acoustics and vibrations here the thermal performance is of particular interest. Due to the very low weight the thermal inertia is very low. For compensation of this property this deck element was designed with an integrated piping system for simulating the thermal behaviour of a heavy construction, furthermore the characteristic of a heating and cooling ceiling could be reached, depending on the supply temperature.

Prototypes of these new deck panels were produced and implemented into the research building of the Institute of Steel and Light-weight Constructions, RWTH in Aachen. A detailed scientific programme was performed to work out the thermal capabilities of these elements using a detailed monitoring system, heat meters and infrared surveys. In parallel numerical investigations were made (FEM-calculations and TRNSYS-simulations) to compare the results and to show further steps for improvements.

The investigations show interesting results: The manufacturing must be properly performed to get sufficient thermal contact from pipes to the ceiling, the response time is low due to the low mass, and the benefit for the indoor climate of light-weight constructions is high with acceptable additional costs.

## INTRODUCTION

The deck element in the scope of this investigation is a laser-welded steel sandwich panel (LSP) with vertical webs in a Vierendeel system. Figure 1 shows this element, which is originally used for decks in shipbuilding, and gives the range of dimensions, in which this panel is available, the maximum span amounts 10 m. The column indicated with “RWTH” shows the dimensions of the elements used for testing in the RWTH Modular Research Building (see below). The very low depth could only achieved by penetrating the laser-weld beam from the outside. These deck elements have a high stiffness at a very low mass. These properties make the panels interesting for highly prefabricated construction systems.




| | from [mm] | to [mm] | RWTH [mm] |
|---|---|---|---|
| Width | 500 | 3000 | 1800 |
| Length | 1000 | 10000 | 5400 |
| t | 2 | 10 | 3 |
| p | 120 | 120 | 120 |
| hs | 40 | 100 | 80 |
| ts | 3 | 4 | 4 |

Figure 1: Laser welded steel sandwich panel with upper deck plate, vertical webs and lower deck plate (left), dimensions of laser-welded panels (right)

One problem of having this very low mass is the missing thermal inertia, therefore a solution to compensate this disadvantage was developed and tested. A steel pipe meander was integrated in the panel to create a heating / cooling ceiling resp. a thermally activated building component (Figure 2). The denomination is not clear-cut, on one hand, the hydronic system is integrated in a structural component similar to a concrete core cooling, on the other hand it behaves like a cooling ceiling

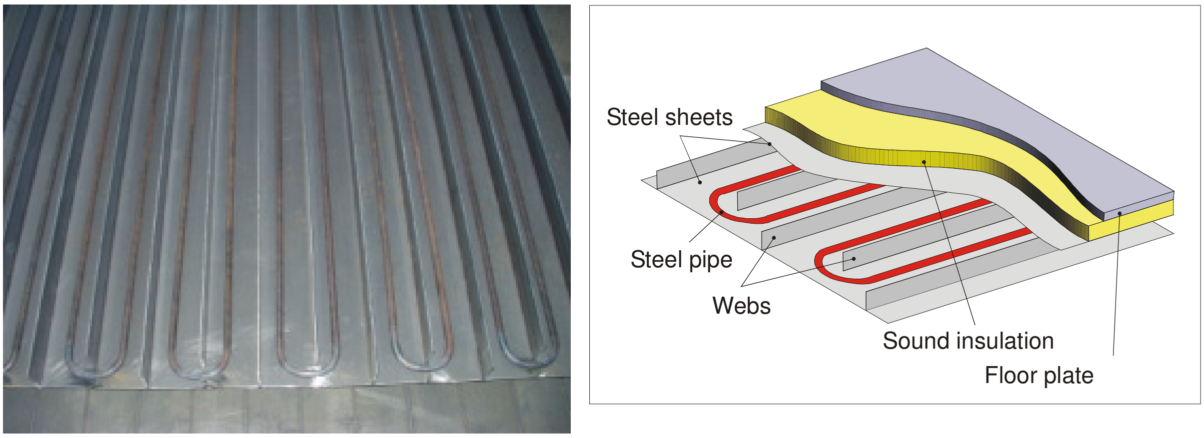



Figure 2: Integration of steel pipes in the steel deck system (left: steel pipes in the module before welding the upper steel sheet, right: principle of the completed deck system)

## IMPLEMENTATION AND TESTING OF THE DECK SYSTEM IN A RESEARCH BUILDING

In 2005 the Institute of steel and light-weight construction, RWTH Aachen University, in collaboration with the german association IFBS (Industrieverband für Bausysteme im Metallleichtbau, Düsseldorf), erected a research building using light weight, prefabricated components made of steel. Drawings of the building are given in figure 3, figure 4 shows the erection and figure 5 the completed building. One objective of this research building is the measurement of the thermally activated LSP. The test room in the center of the ground floor is equipped with these elements.

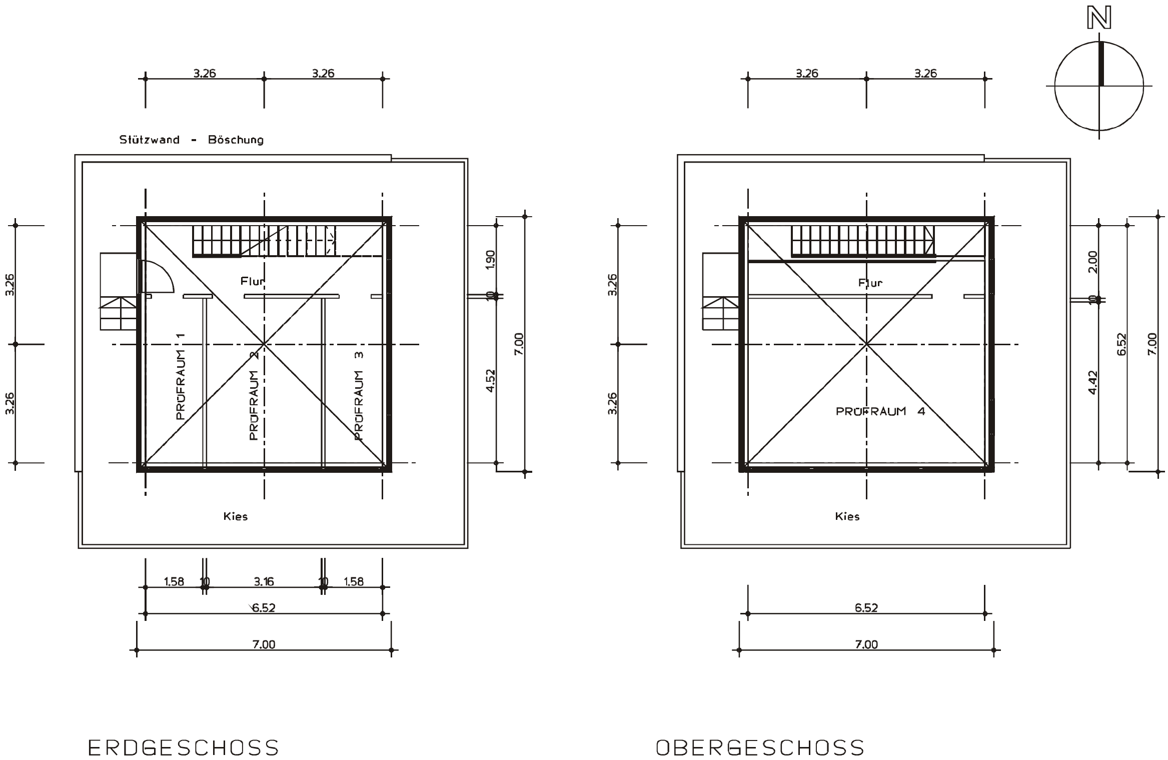



Figure 3: Ground plan of modular research building (left: ground floor, right: upper floor)

Figure 4: Erection of Modular Research Building

Figure 5: Modular Research Building, elevation North-West (left), South-East (right)

**TESTING EQUIPMENT FOR DECK SYSTEM**

The two active deck elements are feeded by a refrigerated circulator, providing pre-heated or pre-cooled water. Various valves are integrated in the circuit to allow different running modes (only one panel active or both in parallel or serial connection). Each panel has a heat meter for measuring volume flow and the consumption of heat resp. coolth (figure 6). Additionally heat flux plates and an infrared camera were used to get more reliable data by using different measurements at once.

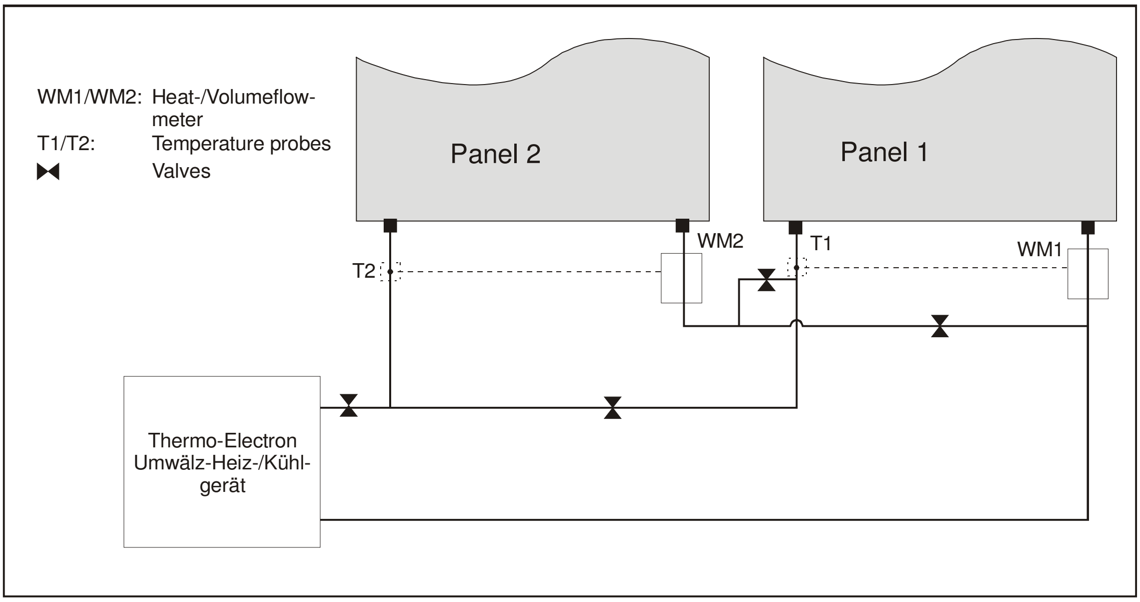



Figure 6: Sketch of testing set-up

Measurements were made for heating and cooling, due to the lack of space only the cooling results are presented (further results: see [4]). Figure 7 shows the specific cooling power depending on the mean temperature difference water – room. In the diagramm results taken from the heat meters and by heat flux meters in combination with infrared surveys are shown. Results between ca. 30 and more than 45 W/m² were measured at temperature differences between 6 and 8 K (room – mean water temperature).

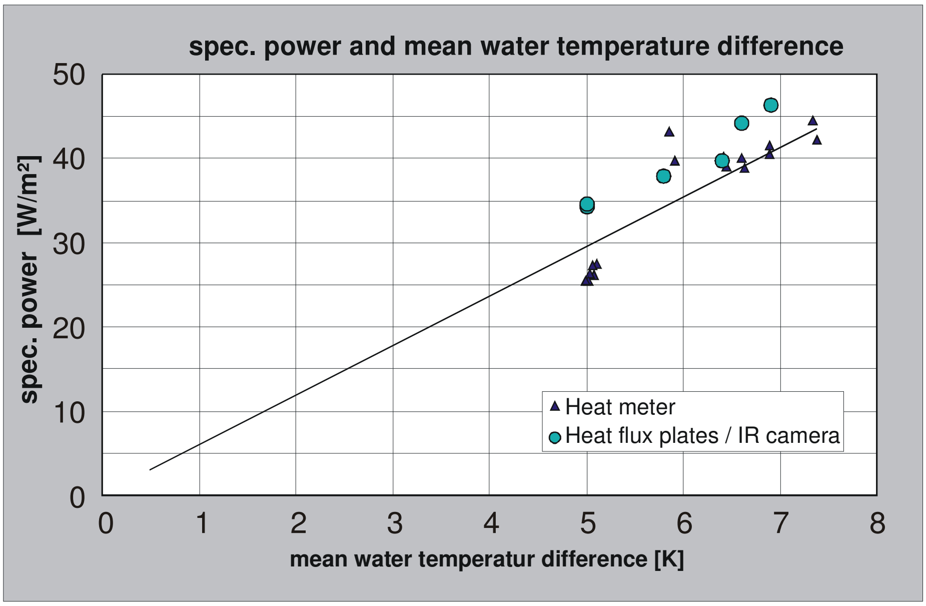



Figure 7: Measured cooling power of active deck element, cooling mode

An infrared survey from the ceiling were taken to get detailed information about the temperature distribution (figure 8). The view on the lower side of the panels shows some remarkable aspects: The steel pipes are sticked-welded to the lower deck plate of the section every 100 cm, these positions can be identified as "cold spots", here is a good thermal contact guaranteed. In between the contact is more or less random – in some parts there is good contact also between the welded points, but in the majority part the temperature is higher – the thermal contact is not sufficient.

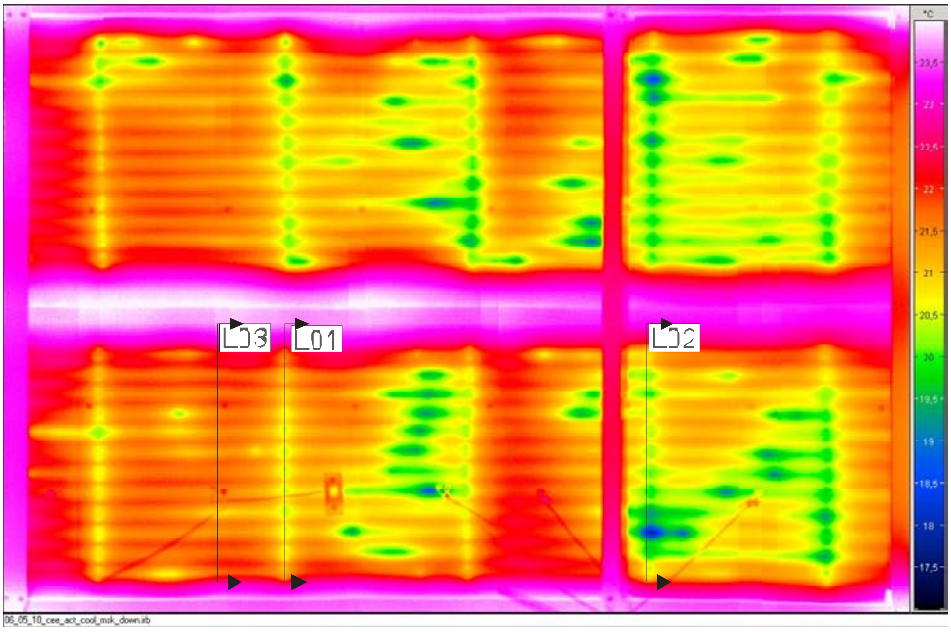


Figure 8: Infrared survey of active deck element, cooling mode (view underneath the steel slab)

**FEM-CALCULATIONS**

The tested deck element was also numerically investigated. A representative sectional model was used for a FEM-study. Two different cases were considered: The pure LSP with the pipe and a complete deck system including insulation and floor plate (figure 9). These two variations were tested in the research building, too.

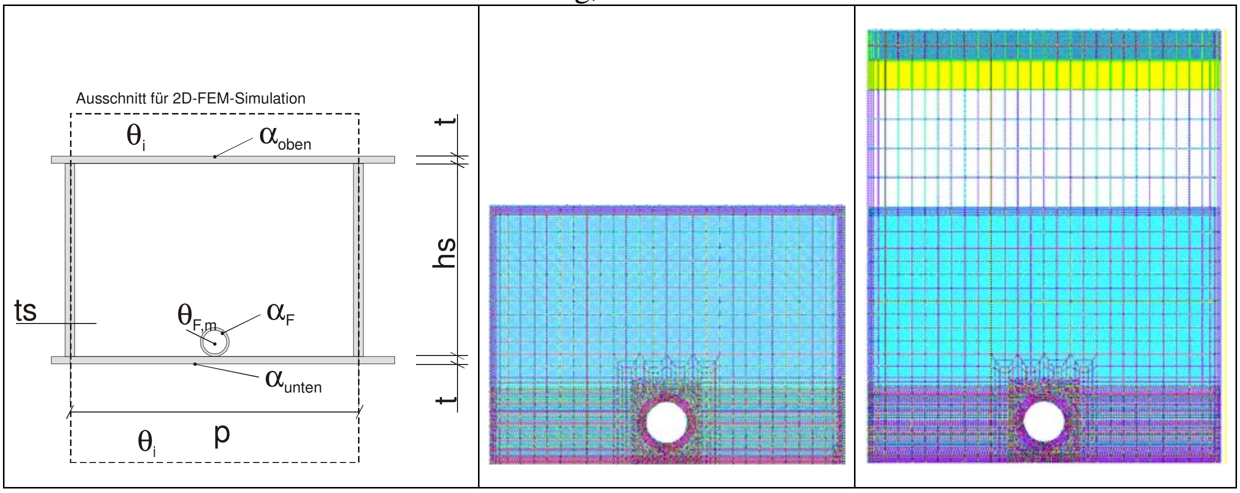



Figure 9: FEM-model of thermally activated LSP (left: sketch with boundary conditions, mid: FEM-model without flooring, right, FEM-model with insulation an floor plate)

The following boundary conditions were taken into account [2],[3]:

| | |
|---|---|
| Mean water temperature $\theta_{F,m}$: | 18 °C |
| Room temperature $\theta_i$: | 26 °C |
| Heat transfer coefficient $\alpha_{top}$: | 6.7 W/m²K |
| Heat transfer coefficient $\alpha_{unten}$: | $8.92\ (\theta_i - \theta_{F,m})^{0.1}$ W/m²K |
| Heat transfer coefficient water/pipe $\alpha_F$: | 200 W/m²K |

Figure 10 shows the results of the FEM-calculations. Without insulation a part of the coolth reaches the floor, the ceiling temperature is about 20 °C, the floor approx. 22 °C. If the insulation and floor plate is added, nearly all coolth is transferred by the ceiling (temperature 19 – 20 °C), the floor temperature is close to the room temperature.

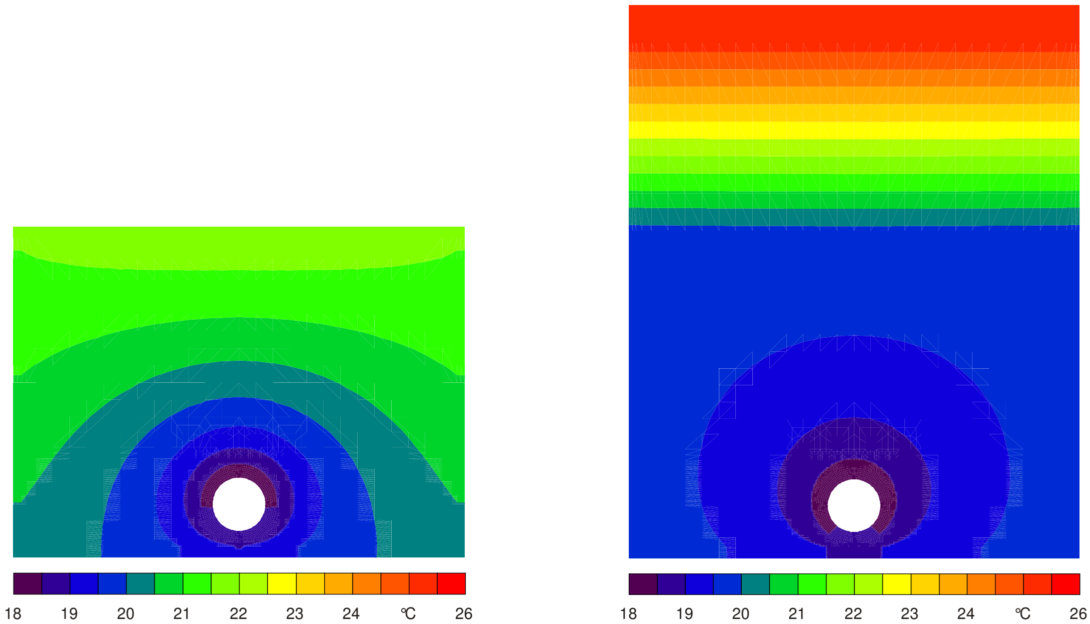



Figure 10: Results FEM-calculation (left: without flooring, right: with insulation and floor plate)

Based on these results the cooling power for various temperature differences was calculated (Figure 11); the diagram shows additionally curves for existing cooling ceilings, furthermore the measured results as shown in Figure 7 are marked. The FEM-results show a high performance of the thermally activated LSP, on the other hand, the measured results are significantly lower. This difference was studied in detail by an analysis of the IR-survey and a variation of the FEM-calculations (Figure 12).

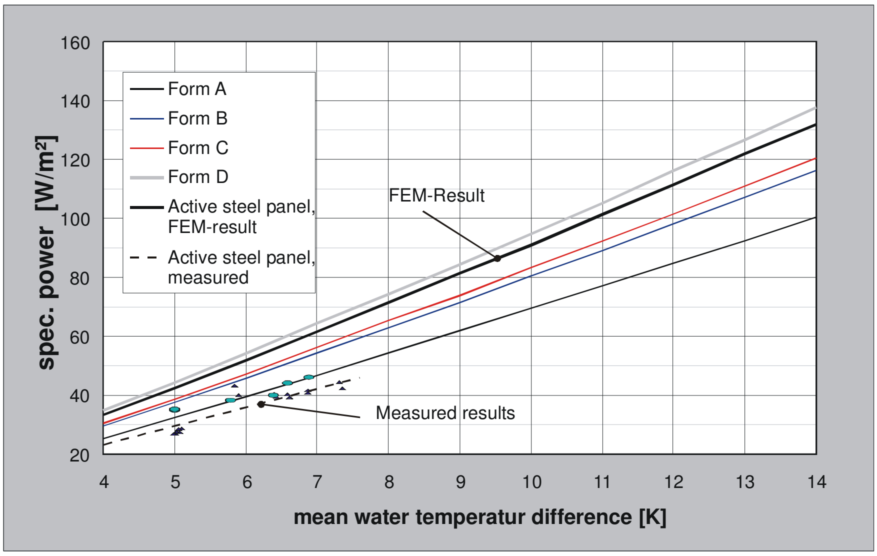



Figure 11: FEM-result (thermally activated LSP with insulation and floor plate), in comparison with conventional existing cooling ceilings (Form A to D, [1]) and the measured results

The comparison of Figure 12 shows, that very small air gaps between the pipe and the sheet lead to a significant loose of performance. The measured section L3 is close to the calculated result for a 1 mm air gap, on the other hand the measured cold spots (see L02) reach the temperature

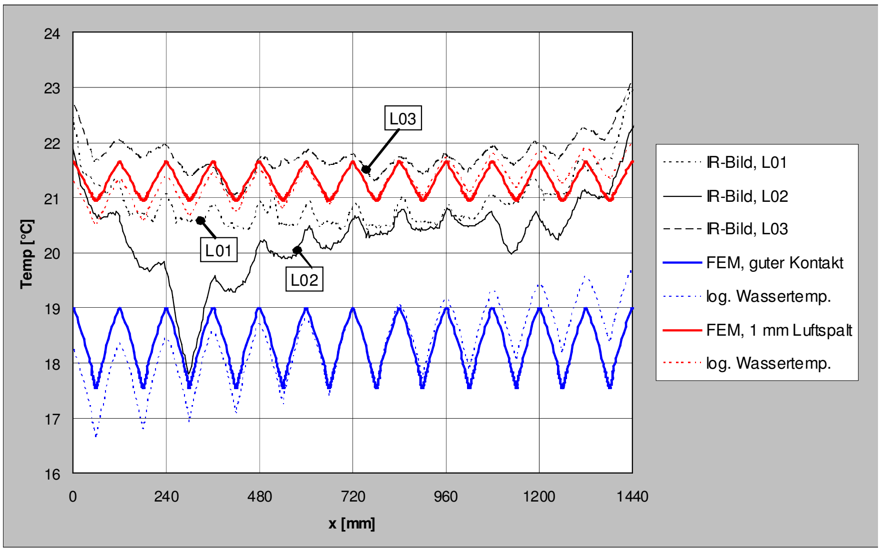



Figure 12: Comparison of FEM-results (good contact and 1 mm air gap) and sections of the IR-survey (as marked in Figure 8)

## RESULTS

The thermal activation of a laser-welded steel sandwich panel is possible. The thermal performance was tested by measurements and in parallel investigated with numerical calculations. The theoretical performance is very good, a specific cooling power of 70 W/m² by a mean temperature difference water – room of 8 K was calculated, which is in the top range of existing cooling ceilings. The measured results are lower, a value of ca. 48 W/m² at the same temperature difference can be extrapolated from the measurements. The main reason for this deviations was identified: The steel pipes have good contact to the lower steel sheet only at the fixing points, in between frequently an air gap exist, whereas small gaps (1 mm) lead to a significant loss of power

## DISCUSSION

Generally the deck system "LSP" presented in this paper has the potential for a high cooling performance, as the FE-calculations show. To reach this value in practice, the contact between pipe and sheet has to be worked out carefully. The punctual stitched welds lead to unwanted decrease of the cooling power. A continuous welding or other techniques (glue, thermal paste, e.g.) to improve the thermal contact will bring the practical results closer the calculated values.

## ACKNOWLEDGEMENT

The investigations has been carried out with a financial grant of the Research Programme of the Research Fund for Coal and Steel within the project EEBIS - Energy Efficient Buildings through Innovative Systems in steel (RFS - CR – 03017). The Modular research building was supported by IFBS (Düsseldorf, D), the laser-welded steel sandwich panels by Meyer Werft (Papenburg, D). These funds are greatly acknowledged.

## REFERENCES

1. Recknagel, H., Sprenger, E., Schramek, E., Taschenbuch für Heizung und Klimatechnik, 72. Auflage, Oldenbourg Industrieverlag, München, 2005
2. Gütegemeinschaft Flächenheizungen und Flächenkühlungen e.V.: Allgemeine Güte- und Prüfbestimmungen für die Systeme der Thermischen Bauteilaktivierung (Betonkernaktivierung) RAL – GZ 964
3. Glück, Bernd RAL Gütesicherung für Systeme der thermischen Bauteilaktivierung; HLH Heizung Lüftung Haustechnik 2004, Heft 5
4. Research Programme of the Research Fund for Coal and Steel, Project EEBIS - Energy Efficient Buildings through Innovative Systems in steel (RFS - CR – 03017), final report (in preparation), 2007