Energy Demand Evaluation of a Novel Individual Heating System using Infrared Panels for Long Distance and Regional Trains

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Abstract

There is an increasing urgency to shift road transportation of passengers to more environmentally friendly modals such as railways. Individual acclimatization, a commonplace for cars and airplanes is still fiction for railways and one challenge for the modal shift. A joint collaboration between Deutsche Bahn Systemtechnik (DB-ST) and the German Aerospace Center (DLR) conducted a series of experiments at the "Demonstrator for Innovation for Traveller Comfort and Air Conditioning" (DIRK) in Minden to analyse the capability of individual heating elements, especially infrared panels, to maintain or increase the thermal passengers' comfort, as well as the possibility to reduce the cabin temperature in case of heating, thus allowing a reduction of the heating energy demand while at least maintaining the same thermal comfort level. For this purpose, a system architecture was developed which consists of a control and a measuring system. The control system allows to set the comfort levels of various heating elements by each user via an individual tablet. The measuring system records the electrical power of the respective seats and allows them to be evaluated. This paper introduces the system architecture designed for controlling and measuring the electric energy demand of the heating elements, as well as the power characterization of infrared panels related to the input signal.

Keywords: Thermal comfort, energy demand reduction, acclimatization, controlling system

1. Introduction

The "Demonstrator for Innovation for Traveller Comfort and Air Conditioning" (DIRK) is an ICE-2 train wagon from DB which was converted into laboratory in a project between DLR and DB-ST (see Figure 1) [1]. The DIRK is used for thermal related research, taking advantage of the synergy between academy and industry for developing future technologies for railway and continues the preliminary work of DLR in the area of thermal comfort of the tests in the generic train laboratory Göttingen from 2019 [2], [3]. Next to investigations on illumination and overall ventilation, a generic Infrared panel configuration was analysed in combination with floor-based displacement ventilation highlighting the potential of a combined individual heating with a reduced overall temperature in the compartment. Based on numerical simulations the positive effect on the personal comfort evaluation and the energy saving potential was also predicted by [4].

Figure 1: DIRK research ICE laboratory carriage. Left outside view and right: inside view.

For the measurement campaign inside the wagon, 24 seats were equipped with three individual IR panels and two seat heater elements to evaluate the capability individual heating system to increase or keep the same level of thermal comfort with equal or lower cabin temperatures in case of heating. The investigated measurement scenarios are detailed in the paper #0289, while the paper #0459 focusses on the psychological evaluation of the test subjects. The focus of this report is to describe the control system and electric energy measuring system, as well as the energy related results.

2. Methodology

The complete system can be separated into a control system for the heating elements installed at the 24 seats and a power measuring system (see diagram Figure 2). The measuring system (orange) logs the voltage and current demand by each seat during the experiments. The control system (green) is responsible for the communication between the individual tablet or smartphones and the server, as well as the communication between the server and the controllers. The power level of the heating elements is regulated by the DALI (Digital Addressable Lighting Interface) controllers. They are normally used to control lighting operating devices.

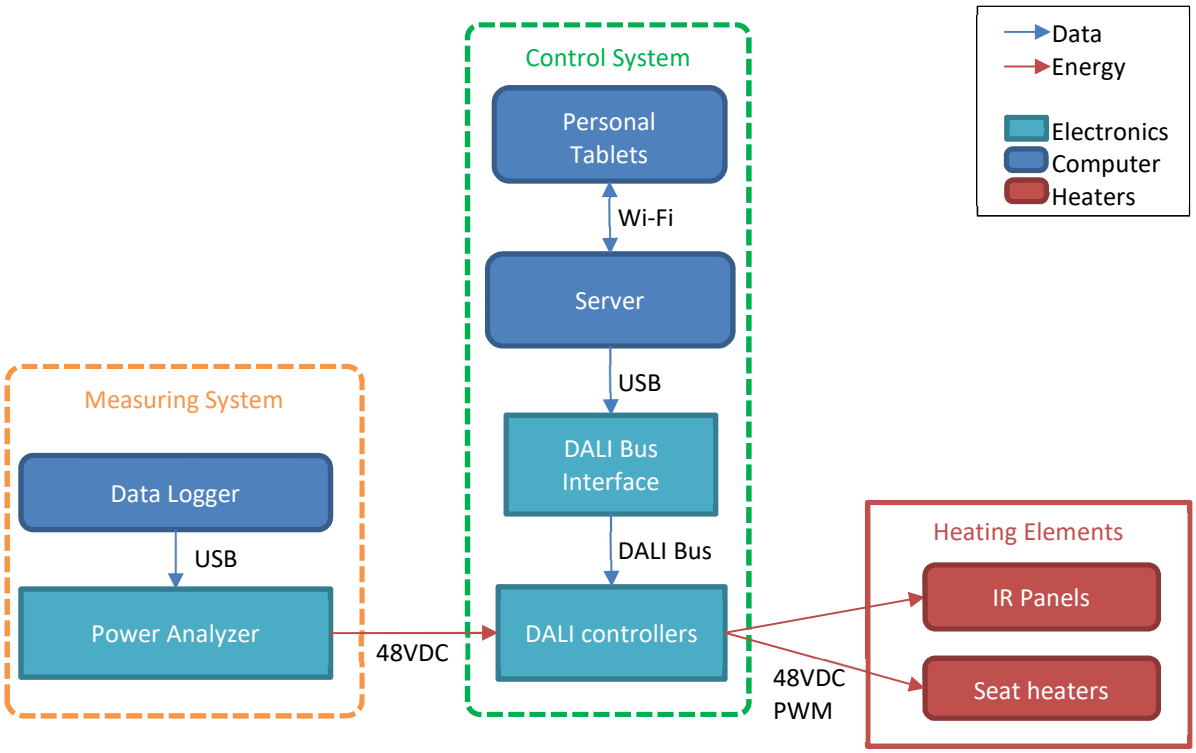


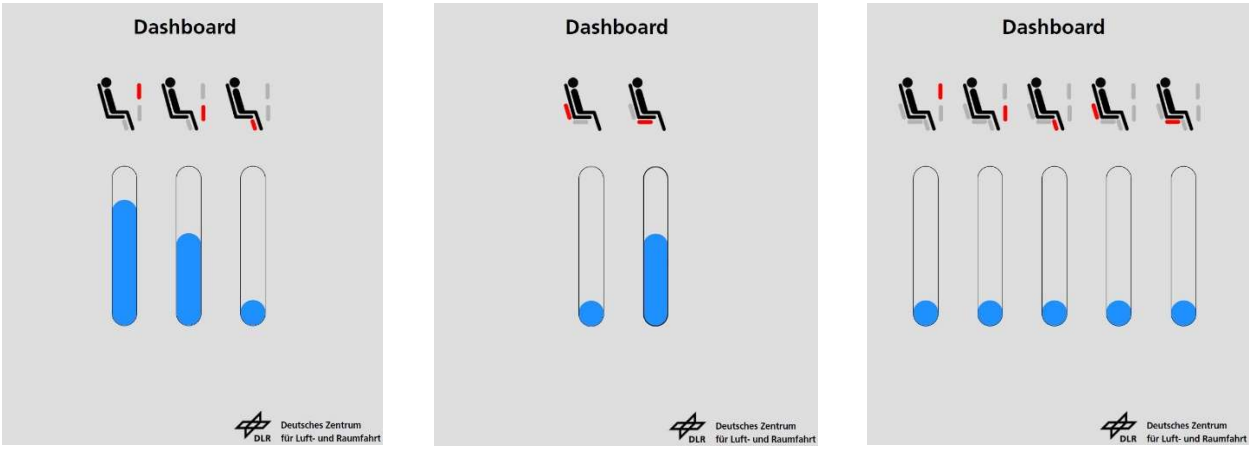
Figure 2: System Architecture

2.1 Control System

The control system regulates the personalised seat heating setting. For this purpose, the thermal energy requirement can be entered on a tablet via a Python GUI. These are then transmitted to a server via WIFI. This server receives the data, processes it and assigns it to the respective seat. It then transfers the data to a DALI bus interface via a USB adapter. This converts the data into a bus format and sends it to the corresponding DALI controller. The DALI controller regulates the current to the respective heating element for individual seat heating adjustment.

As part of the research on a new type of heating system individual tablets were given to the users. On these tablets the users could separately control all of the heating elements of their own seat (positions of the heating panels in the seat area: back, buttocks, and lower thigh or in the front area: upper body and leg, see Figure 3). Before each experiment the users were instructed on how to use the tablets.

Depending on the experiment being conducted, the user was allowed to control only the infrared panels (Figure 3 a), only the seat heaters (b) or both set of heating elements in five gradations (c) on the tablet. The disabled heating elements were kept hidden from the users and turned off.



a) b) c)

Figure 3: User interface of the control system for different experiments

The researcher interface (Figure 4) can control every panel independently and as a group of the respective seat, as well as record the heating elements states to reproduce the experiments in a later moment.

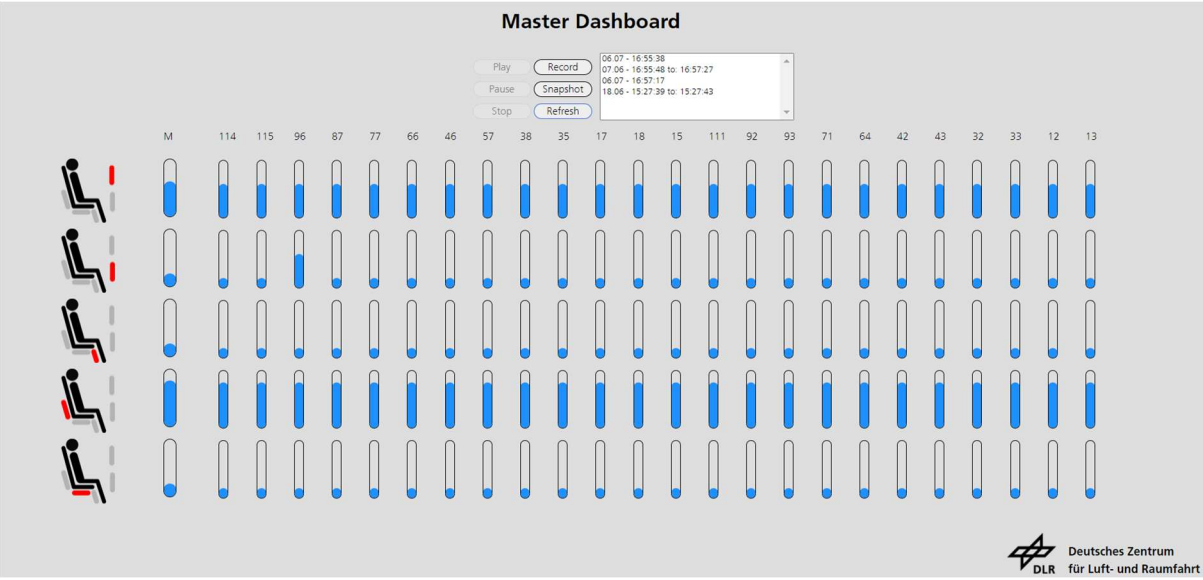
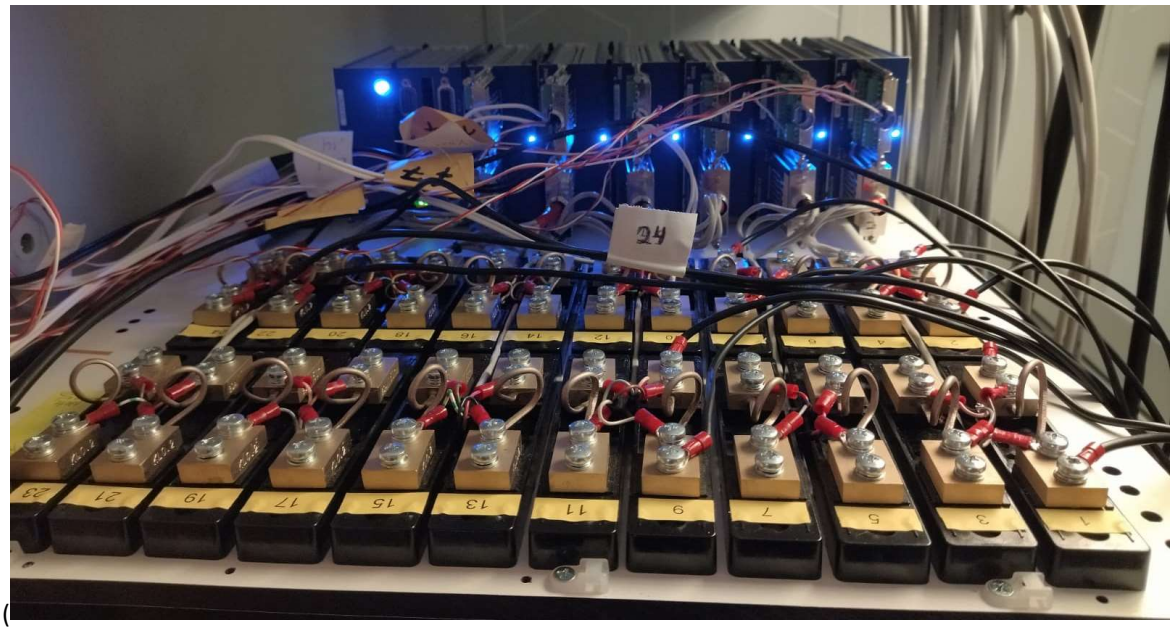


Figure 4: Researchers interface of the control system

The server query requests from the tablets (either users or researchers) and changes the power level of the heating elements using the DALI communication protocol. For the same power level, the electrical power demanded at the 24 seats differs thus making the recording of the latter crucial.

2.2 Measuring System

Two different measuring systems were used for the acquisition of the energy demanded for each seat during the experiments. The commercial ZES Zimmer LMG671 power analyzer was used to measure six selected seats at the beginning of the measurement campaign, and later, in order to overcome the limited number of measurable channels, a measuring system developed in-house using the IMC CANSASflex-C8 as signal amplifier and data logger was used to measure all 24 seats simultaneously (Figure **5**).



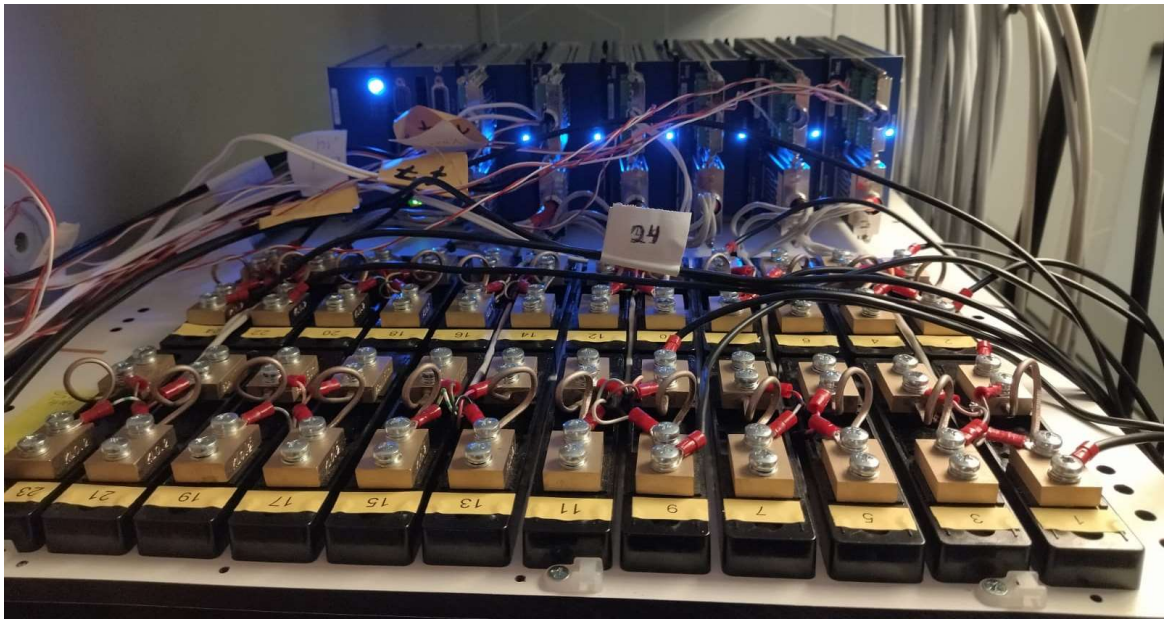


Figure 5: Measuring system. Voltage is measured directly in parallel by the CANSASflex-C8 modules, and current is measured by a small voltage drop induced by resistors (shunts) connected in series.

3. Results

The power demand of the IR panels is limited using a PWM signal, in order to reduce the surface temperature exposed to the passengers to a safe level. The visualization of the heat radiation on an exemplary seat is shown in Figure 6.

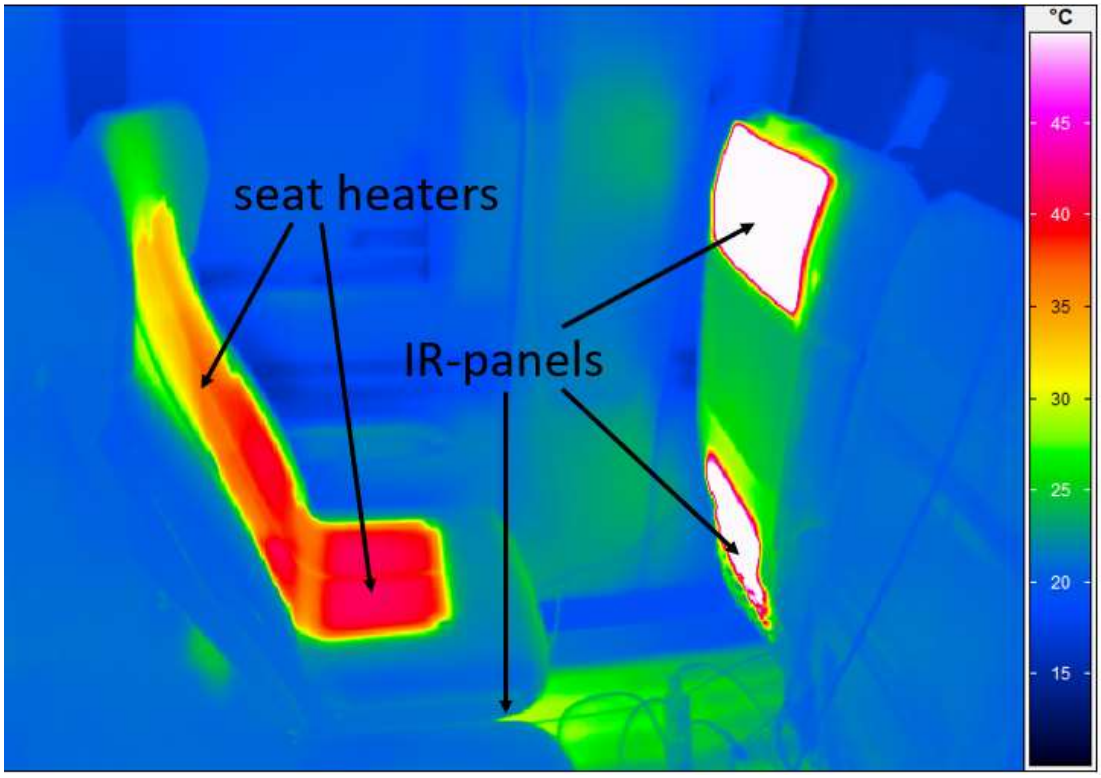


Figure 6: Thermography of the 3 IR panels and 2 seat heaters. The IR legs panel is hidden below the seat.

For different positions of the IR elements (blue: top, red: front, green: legs), a different electrical power was assigned to each heating element depending on the power level set by the user (shown in Figure 7).

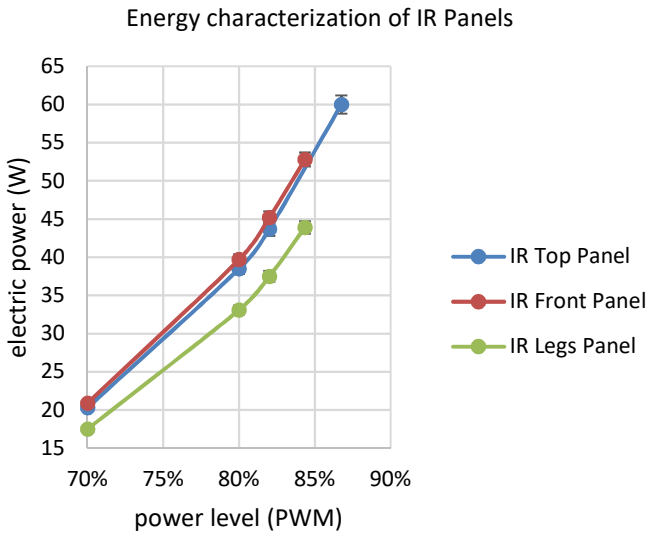


Figure 7: Power demand of the IR panels for different power level

4. Conclusions

The proposed system is able to control and measure the power level of the heating elements individually. The individual heating elements are able to influence and at least maintain the thermal comfort in lower cabin temperatures (objectively evaluated with sensors in the paper #0289, and subjectively evaluated with test subjects in the paper #0459).

The reduction of the temperature in the cabin along with individual comfort systems (IR heating elements and seat heating) are able to maintain the same level of comfort, can lead to a reduction of overall energy consumption for acclimatization in cold climates. However, the energy savings alone are not enough to financially justify its implementation along the life-cycle of passenger trains, but could be an effective tool increase the comfort and the attractiveness of the railway transportation.

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