Passive Cooling Technologies for Reducing the Heating of Containers

Tanja Vetter, Norbert Schneider, Heinrich Dinnebier

(Dr. Tanja Vetter, Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB), Institutsweg 1, 85435 Erding, wiwebposteingang@bundeswehr.org)

(Norbert Schneider, Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB), Institutsweg 1, 85435 Erding, wiwebposteingang@bundeswehr.org)

(Heinrich Dinnebier, Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB), Institutsweg 1, 85435 Erding, wiwebposteingang@bundeswehr.org)

1 ABSTRACT

Containers are widely used within the Bundeswehr, especially in military camps. These containers often overheat, most notably in southern areas. High temperatures can cause problems like accelerated ageing of stored material or failure of electronic equipment running inside. Air conditioning systems can counteract this but consume high amounts of energy and require regular maintenance.

Passive cooling technologies, i.e. technologies that cool without requiring additional energy, are intended to alleviate this problem. The simplest passive cooling technology is shading e.g. by applying additional roofing or camouflage nets. However, the disadvantages are the additional required material and the assembly and disassembly whenever the container is moved.

New technologies for passive cooling are based on different mechanisms: Coatings can reduce the solar heat-up either by being highly reflective or through a novel mechanism called passive daytime radiative cooling (PDRC). Another technique is the use of heat storage panels, which contain phase change material (PCM) to minimize the daytime heating of the containers. Furthermore, spacer fabrics on the surface of containers allow cooling based on the chimney effect.

To evaluate the passive cooling power of the different technologies, containers were equipped with three different cooling coating systems, heat storage panels, spacer fabrics, roofing and camouflage net. Two regular containers were used as a baseline. Temperature was measured at each container at different spots inside and outside. Further, every container was equipped with an air conditioning system and a power meter to measure energy consumption.

All containers with passive cooling technologies showed lower temperatures compared to the reference containers. The power measurements confirmed a lower energy consumption of the air-conditioning systems. PDRC coatings, PCMs und spacer fabrics show a better passive cooling power than shadowing like e.g. roofing. PDRC coatings were the most effective technology overall in this setup, but dependent on the application scenarios, the other passive cooling systems can also be powerful.

2 INTRODUCTION

In times of global warming, solutions for cooling down surfaces are widely asked. Within the Bundeswehr, surfaces of containers - especially in southern military operational areas - heat up fast, which also results in high temperatures inside the containers. This can lead to accelerated ageing of sensitive storage material or device failure due to overheating. Cooling by using air conditioning systems requires high energy consumption and regular maintenance of the devices. Especially in areas with weak infrastructure, the energy supply can only be guaranteed by diesel generators, which is why energy consumption should be as low as possible.

Passive cooling technologies, i.e. technologies that cool without requiring additional energy, seem to counteract this problem. They can provide an environmentally friendly way to regulate temperature without relying on active cooling systems. One of the simplest passive cooling technologies is shading. Actually, containers are shaded with additional roofing or camouflage nets. Disadvantages here are the additional material required and the assembly and disassembly when moving and during storms.

A relatively new technology for passive cooling is based on coatings. These have the advantage that no additional material has to be transported or assembled after the paint has been applied. Coatings containing e.g. ceramic or BaSO4-particles, which are already commercially available, enable slower heating and lower surface temperatures due to high reflection in the solar spectrum. Based on findings from Columbia University, a Canadian startup developed a porous polymer layer that combines high reflection in the solar spectrum and high emission of thermal radiation (passive daytime radiative cooling - PDRC) [Mandal 2018]. Under ideal conditions, temperatures below ambient temperature should be achieved.

Beside coatings, latent heat storage plates containing phase change material (PCM) applied outside of e.g. containers prevent surfaces from heating by storing the heat. As long as the heat storage capacity is not exceeded the container surface, and also the volume of the container, does not heat up. PCM-boxes were already tested in a real-size experiment and showed a good behavior in reducing heat up [Sonnick 2020]. At least, spacer fabrics also can help cooling down surface due to an air flow induced by convection inside the fabrics. [Pires 2011]

All technologies have advantages and disadvantes regarding different points like cooling power at different weather scenarios, application, stability and the possibility of optical adaptation. Especially the assessment and the comparison of the cooling power of the different technology based on literature data is challenging. Therefore, all technologies are be applied on containers standing next to each other. Measuring the temperature inside and outside allows to evaluate the cooling performance of the different technologies. Further, the power of the air conditioning systems inside the containers is measured to investigate possible energy savings.

3 THEORETICAL BACKGROUND

3.1 Passive Cooling Technologies

3.1.1 Shading Systems

Passive cooling through shading is an effective method to protect buildings or containers from excessive heat, especially in warm climates. By strategically placing camouflage nets or roofing, direct sunlight exposure is reduced. This leads to decreasing heat absorption, a decelerated heat up and energy savings. The advantage of this technology lies in its simplicity. The disadvantage is, that additional material and good construction skills are required for applying safe and efficient shading structures. [Bhamare 2019, Kamal 2012]

3.1.2 Radiative Cooling

Radiative cooling can be achieved by applying coatings which contain thermal radiation emitters emitting heat in form of infrared radiation to lower the temperature of surfaces and reduces heating from solar radiation inside buildings or containers. Passive daytime radiative cooling is a specific application of passive radiative cooling and operates during daylight hours. PDRC coatings are based on materials which reflect sunlight and emit thermal radiation to cool down surfaces even when the sun is shining. By selectively reflecting sunlight while efficiently emitting heat, these materials achieve significant lower temperatures than traditional coatings. The surface temperature with PDRC coatings can even be lower than ambient temperature. PDRC coatings are based on different technologies like e.g. using BaSO4-pigments, different shaped ceramic particles or applying a porous polymer layer. This technology is most recommended for hot, dry climates with high global irradiation but also can be used in other climates. A disadvantage of these paintings lies in their limited colour range: with increasing darkness of the colour lower cooling power is available. [Bhamare 2019, Chen 2021, ECT 2007, Mandal 2018, Mandal 2020]

3.1.3 Phase Change Material

Phase change material-based latent heat storage plates absorb or release heat during their phase transition. Therefore, they are appropriate to store and release thermal energy. PCM, often based on parrafins or salts, are integrated into plates and absorp heat at their transition from solid to liquid and vice versa. Using PCM plates enables compact and effective storage of large amounts of thermal energy at relatively low costs. The disadvantage is the limited heat storage capacity. If the capacity is exceeded, the plates have to be reconditioned by cooling down (e.g. at night) for giving off the stored heat. [Oropeza-Perez 2018, Sonnick 2020]

3.1.4 Spacer Fabrics

Using spacer fabrics on surfaces allows the cooling of buildings or containers without relying on active cooling systems. In this technique, the spacer fabrics efficiently dissipate heat with an airflow caused by convection. [Pires 2011]

4 EXPERIMENTAL

For testing the passive cooling technologies in a real size scenario, ten 10 ft containers are equipped with the different technologies (Fig. 1). Two reference containers are coated with typical military coatings approved by TL 8010-0002 in RAL 6031-F9 bronce green and RAL 1039-F9 sand beige (C1 and C2). The containers C3 and C4 are equipped with the PDRC Coating PolyFrostTM by the canadian startup Chillskyn, where C3 is only coated on the roof. The coating Supertherm by SpiCoatings is applied on C5 and C6 is coated with Pleyers800® by Porviva. Latent heat storage plates with a phase transition temperature of 25°C are mounted on container C7 by MELT. The used spacer fabrics on Container C8 are from Müller Textil. Additional additive manufactured chimneys on the roof shall help to cool down the roof efficiently. On the last two containers, the shading was recreated using roofing (C9) and camouflage nets (C10). All container doors face south.

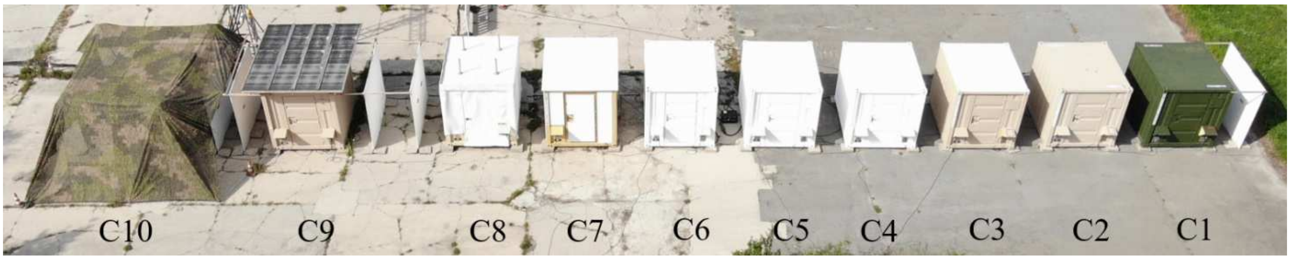

Fig. 1: Test setup for passive cooling technologies on 10 ft containers (from left to right: camouflage net, roofing, spacer fabrics, coating Pleyers800®, coating Supertherm, PDRC coating ChillSkyn, PDRC coating ChillSkyn roof only, reference sand beige, reference bronce green)

The temperature data is recorded with type K thermocouples and Pico TC-08 data loggers. Thermocouples are applied outside on the roof and on the door and inside on the roof, the door and in the middle of the containers. Further, Trotec BL 30 climate data logger are placed inside the containers. Thermal images of the containers are made with DJI Mavic 2 Enterprise drone equipped with a Mavic 2 Enterprise Dual thermal imaging camera und Mavic 2 Enterprise Dual vision camera.

The containers C2 to C10 contain air conditioning systems K3RNB9A from Gree. The power of the air conditioner is measured with the Sefram DAS 1400 portable recorder and the appropriate current clamps and adapters.

By using a weather station, the global radiation, rain, wind and temperature are recorded.

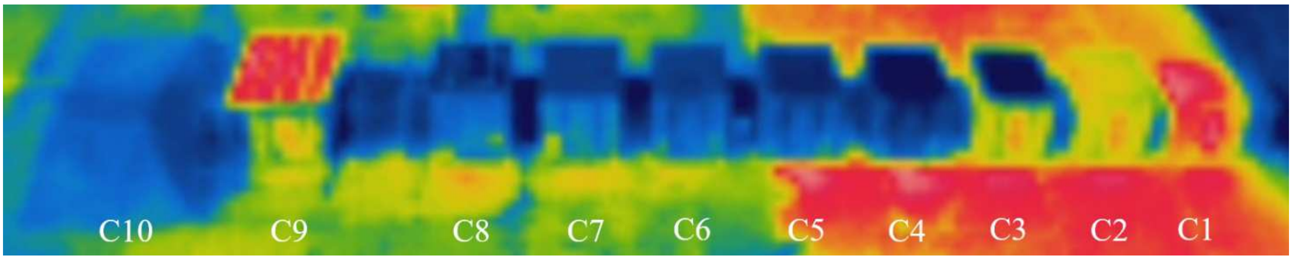

Fig. 2: Thermal image of the test setup for passive cooling technologies on 10 ft containers (from left to right: camouflage net, roofing, spacer fabrics, coating Pleyers800®, coating Supertherm, PDRC coating ChillSkyn, PDRC coating ChillSkyn roof only, reference sand beige, reference bronce green)

5 RESULTS

Thermal imaging is a good way to get a qualitative overall impression of the cooling behavior of the various technologies. Figure 2 shows a thermal image of all containers taken with a camera equipped drone. Cooler parts are shown in blue colour, hot parts appear in red colour (detailed assignment of colour to temperature is not available). All containers equipped with a passive cooling technology are blue coloured and show lower temperatures than the reference containers C1 and C2 with the exception of container C9, which has a roof for shading the container. Also noticable are the containers C3 and C4 which have the coolest roofs showed by the deep blue colour. These containers are coated with the PDRC coating PolyfrostTM.

5.1 Temperature measurements

For getting quantitative informations about the cooling power of the different passive cooling technologies, temperature is measured inside and outside of the containers. Figure 3 shows exemplary for the day of 14th august 2023 the maximum temperatures inside and outside of the container. The maximum environmental temperature for that day was 33°C and there was no rain or clouds. Regarding the temperature outside, the container with the PDRC coating shows maximum surface temperatures lower or similar to the environmental temperature. Compared to the reference containers, there is a temperature difference of 23°C to the sand beige one, and even 32°C to the bronce green container. For the other passive cooling technologies, the surface temperature is also lower compared to the reference containers. the maximum surface temperature for all passive cooling technologies can be found at 42°C for the container with the spacer fabrics.

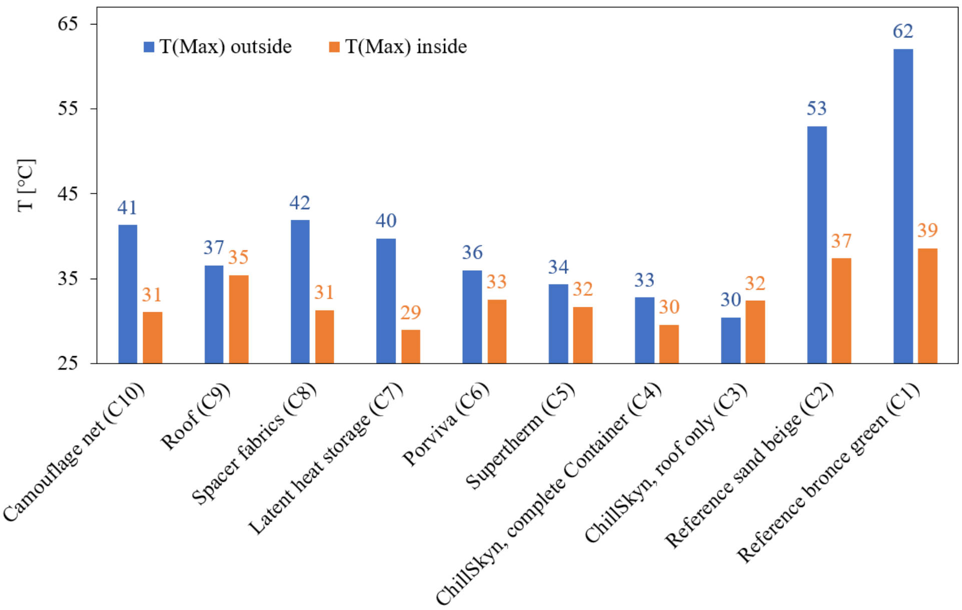

Figure 3: Exemplary maximum temperature for one day (14 August 2023) measured with PicoLog dataloggers outside the container on the roof (blue) and inside the container (orange)

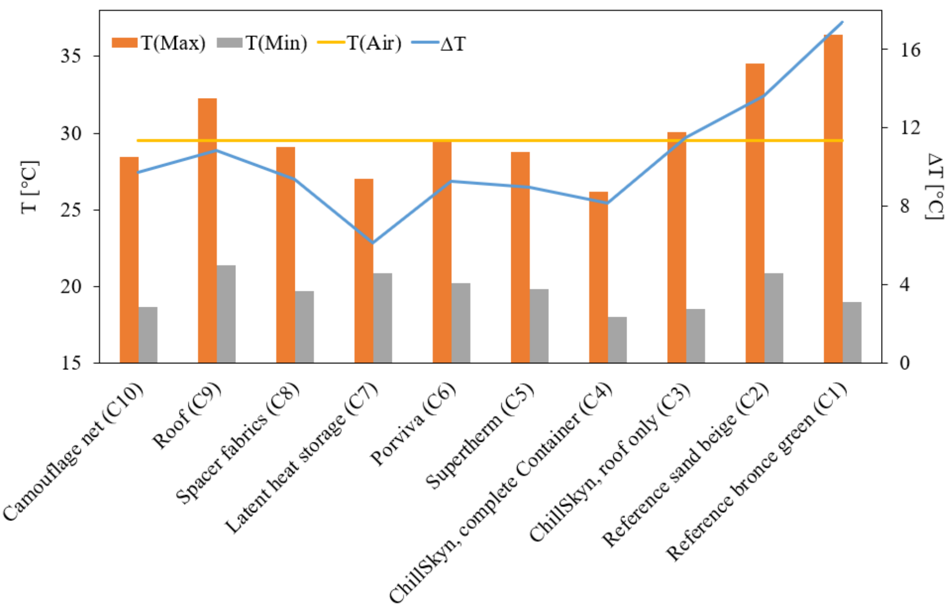

Figure 4: Average maximum and minimum temperature inside the containers measured with the Trotec dataloggers for week 32 and 33 as well as the difference of both temperatures and the temperature of the environment

The temperature inside the containers at 14th august 2023 is for all containers lower and lies between 29°C and 39°C. The maximum temperature inside is also measured in the reference containers. The lowest temperatures can be found at the container with the latent heat storage plates followed by the containers with the PDRC coating. For getting a more general assessment of the cooling power, the average maximum and minimum temperature inside the containers is determined for a time interval of two weeks (see Fig. 4). The difference of the maximum and minimum temperature is also showed as a parameter for temperature fluctuation during a day. By far, the latent heat storage plates and the PDRC coating show the lowest temperature inside the containers. The temperatures for the other passive cooling technologies lie just below or around the environmental temperature with exception of the container with the roofing. The reason for the heating of this containers can be the unshaded front (door area) of the container.

Regarding the temperature difference it is noticeable, that the container with the latent heat storage plates has an average temperature fluctuation during the day of only 6°C. Due to heat release during the night, there is a higher minimum temperature. This can influence the energy saving behavior negatively compared to the other technologies, but for storing material, which is sensitive to periodic temperature fluctuation, this can be the technology of choice.

5.2 Energy saving due to passive cooling technologies

For evaluating the possible energy savings by using different passive cooling technologies, air conditioning systems ran and the power was measured. Figure 5 shows the power for all containers needed in a time period of 2 days. The highest energy consumption can be seen for the reference container (C2) and the container with roofing (C9). The lowest energy consumption can be recognized at the container with the overall PDRC coating (C4) and the container with the spacer fabrics (C8). There is no final explanation yet why C8 performed that well at the power measurements but was unremarkable in the temperature measurements. One idea is, that due to rain, which occurs in the named time period, there was an additional cooling effects based on condensation, but this has to be verified in further investigations. Noticeable is, that the container with the camouflage net (C10) and the container with the Supertherm coating (C5) also show a low energy consumption. The higher consumptions of the latent heat storage plates can be explained by the heat release at night and the temperature of 23°C, which was applied on the air conditioners and lies below the phase transition temperature of 25°C.

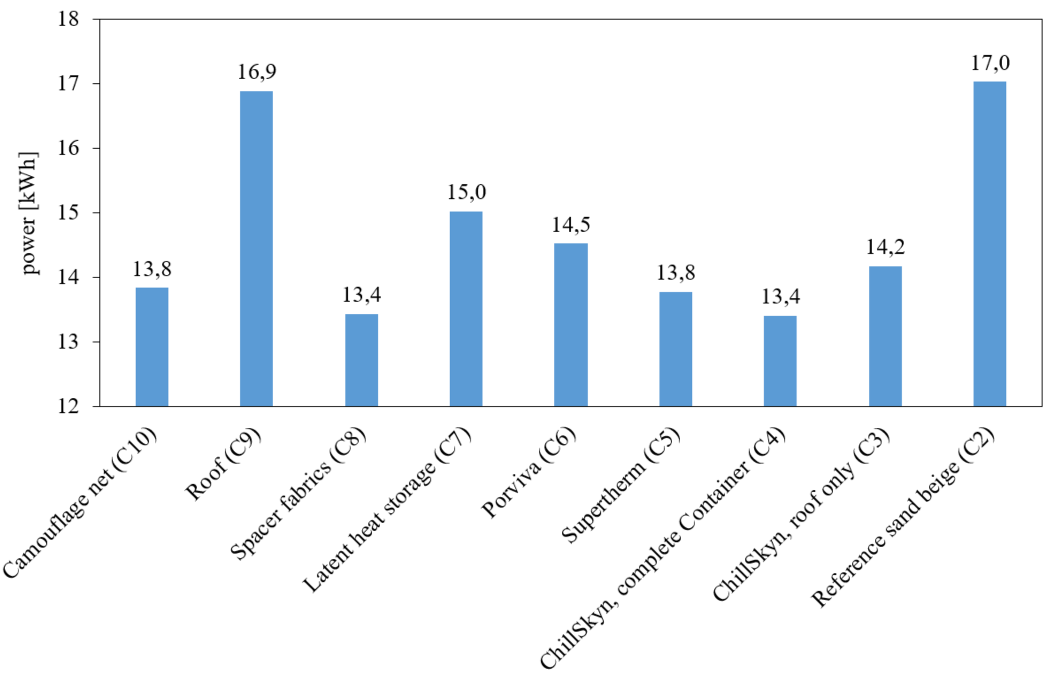

Figure 5: Power of the air conditioning systems running in the operating mode Auto for cooling down to 23°C measured from 22 to 24 August 2023

6 CONCLUSION

The investigations show, that with different passive cooling technologies a reduced heating of the containers can be achieved. An outstanding performance shows the PDRC coating with low surface temperature, low temperature inside the container and low energy consumption. Also the latent heat storage plates show a good cooling behavior inside the containers. Regarding military applications, the PCM plates have the advantage of the adaptility of the surface, where cooling coatings are limited due to decreasing performance with increasing darkness of the colour. Nonetheless, the coatings Supertherm and Pleyers800® show also a good cooling behaviour. The usage of spacer fabrics and camouflage nets can be used for minimizing heating of the containers but with the disadvantage of assembly and disassembly when moving the containers. Overall, passive cooling technologies should be considered as good solutions for reducing heating. The choice of the technology should be dependent on requirements of the application.

In further investigations, the influence of different weather scenarios on the different technologies should be taken more into account. Also aging and the performance of the technologies with contamination should be examined.

7 REFERENCES

Bhamare, K. D., Rathod, M. K., Banerjee J.: Passive cooling techniques for building and their applicability in different climatic zones - the state of the art. In: Energy and Buildings, Vol. 198, pp. 467-490, 2019.

Chen, M., Pang, D., Chen, X., Yan, H., Yang, Y.: Passive daytime radiative cooling: Fundamentals, material designs and applications. In: EcoMat, Vol. 4, Issue 1, pp. 1-28, 2021.

ECT Team, Purdue University: Super Therm - Ceramic Paint Insulation. In: ECT Fact Sheets, Paper 3, 2007.

Kamal, M.A.: An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions. In: Civil Engineering and Architecture, Vol. 55, No. 1, 2012.

Mandal, J., Fu, Y., Overvig, A., Jia, M., Sun, K., Shi, N., Zhou, H. Xiao, X., Yu, N., Yang, Y.: Hierarchically porous polymer coatings for highly efficient passive daytime radiative cooling. In: Science, Vol. 362, Issue 6412, pp. 315-319, 2018.

Mandal, J., Yang, Y., Yu, N., Raman, A.P.: Paints as a scalable and effective Radiative cooling technology for buildings. In: Joule, Vol 4, Issue 7, pp. 1350-1356, 220.

Oropeza-Perez, I., Østergaard, P. A.: Active and passive cooling methods for dwellings: A review. In: Renewable and Sustainable Energy Reviews, Vol. 82, Part 1, pp. 531-544, 2017.

Pires, L., Silva, P. D., Gomes, J. P. C.: Performance of textile and building materials for a particular evaporative cooling purpose. In: Experimental Thermal and Fluid Science, Vol. 35, Issue 4, pp. 670-675, 2011.

Sonnick, S., Erlbeck, L., Gaedtke, M., Wunhder, F., Mayer, C., Krause, M.J., Nirschl, H., Rädle, M.: Passive room conditioning using phase change materials - Demonstration of a long-term real size experiment. In International Journal of Energy Research, Vol. 44, Issue 8, pp. 7047-7056, 2020.