

# Improved humidity and temperature regulation in storage containers

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This thesis presents a redesign of Salland Storage's self-storage containers to significantly improve humidity regulation and prevent internal condensation, due to recurring customer complaints related to internal condensation and moisture damage to stored belongings. The research question answered in this thesis is as follows.

*How can the Self Storage container of Salland Storage be redesigned to significantly improve humidity control and prevent condensation inside the container, regardless of the objects stored inside?*

The research is structured in three main phases: preliminary desk research, empirical testing, and the development and evaluation of proposed solution concepts. The desk research provided a fundamental understanding of the basic principles of humidity, condensation, and ventilation. The relative humidity and dew point temperature were defined as key indicators of condensation risk (National Geographic, 2023; Nguyen et al., 2014) and are used during the empirical testing phase and data analysis.

Empirical testing was conducted over four weeks at the Deventer storage park using temperature and relative humidity sensors placed in two types of containers (*model 2* and *model 5*). During this period, the first two weeks entailed collecting baseline measurements of humidity behavior and condensation risk, the third week entailed adding a moisture source to study its effect on condensation risk, and the fourth week entailed investigating the effect of suspected sources of moisture influx (e.g. the ventilation holes, edges sealed with moisture-permeable foam, and the PU insulation foam).

Analysis of the collected data revealed that relative humidity levels inside the containers frequently exceeded the ideal range of 49–59% (Aal, 2023; Peña, 2024), particularly during the night. The indoor surface and air temperatures came close to reaching and falling below the dew point temperature, which entails significant condensation risk. These effects were most extreme in the *model 5* container, mostly due to the ventilation holes and absence of solar panels on the roof. In contrast, the *model 2* container (with solar panels on the roof) demonstrated reduced thermal fluctuations due to the shading and thermal buffering effects of the panels (Dominguez et al., 2011).

The effectiveness of the current ventilation system was also evaluated. The placement and exposure of ventilation holes significantly influenced both relative and absolute humidity levels. Ventilation hole placement too close to adjacent containers was shown to limit natural airflow (ASHRAE, 2021; Cappuccio, 2021). Additionally, through analysis of the absolute humidity fluctuations, the PU insulation foam (although generally having low moisture permeability) and

the lining material used in the connecting edges of the walls were determined to partially act as moisture buffers (Kirpluks et al., 2014).

Statistical tests (Wilcoxon Signed-Rank test and Mann-Whitney U test) confirmed the significance of observed humidity and temperature differences between test conditions, validating the conclusions drawn from the empirical phase. In future research, a time-series analysis (e.g. ARIMA) should be performed to improve the interpretation of the data, because this type of analysis is more suitable for the type of data collected. However, the data analyses still provided valuable insights into moisture movements and condensation risk within the containers.

Based on these findings, it was determined that the final solution should focus on three key elements: preventing moisture influx, expelling excess moisture, and regulating the air and indoor ceiling surface temperatures. Various possible sub-solutions were explored using further literature review, CAD modeling, and software-based simulations. Examples of explored subsolutions are improving insulation, improving the ventilation system, addition of shade, and solar-powered temperature and humidity regulation systems.

After evaluation, the final proposed concept is a combination of a certified cool roof coating to reduce solar heat gain and a vapor-permeable membrane with adaptive moisture permeability (e.g., SIGA Hygrobrid or CertainTeed Membrain) installed as an airtight layer between the inner sheet metal layer and the insulation layer. This membrane facilitates moisture escape while preventing influx. Additionally, the inclusion of a demand-controlled ventilation (DCV) system is recommended for future integration to further regulate indoor humidity and temperatures. This concept requires minimal installation and maintenance by Salland Storage employees, with most components being integrated during manufacturing. However, the actual performance of this design has yet to be verified under real-world conditions. Therefore, further simulations, physical prototyping, and real-world testing are recommended before full-scale implementation.

In conclusion, this thesis describes the behavior of and challenges relating to humidity and temperature regulation in the Salland storage containers based on literature research and empirical testing, and presents a substantiated and adaptable redesign solution. The proposed design is a robust foundation for continued development toward more climate-resilient storage containers and thus a higher quality of service for Salland Storage customers.

## References

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