INFRANORM®

Sustainable Hall Conditioning - How Two-Stage Adiabatic Cooling Conditions Production Halls Without Relying on Compression Refrigeration

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1. Executive Summary

Rising outdoor temperatures, stricter ESG reporting requirements, and the foreseeable shortage of climate-damaging refrigerants are putting increasing pressure on the climate control of production facilities. Conventional compression refrigeration is reaching its technical, regulatory, and economic limits. Sustainable Hall Conditioning (SHC) from INFRANORM® Technologie GmbH takes a different approach: a two-stage adiabatic cooling system that relies primarily on water rather than compression refrigeration and operates without F-gases or PFAS. Unlike single-stage evaporative cooling systems, the two-stage process achieves lower temperatures while maintaining lower humidity levels. Depending on the project, energy costs and CO_2 emissions for cooling can be reduced by up to 95 percent, and heating costs can be reduced by up to 40 percent through heat recovery. Real-world project data, such as from the BRP-Rotax plant in Gunskirchen, demonstrate annual savings of several hundred metric tons of CO_2 as well as significant reductions in electricity consumption and water withdrawal. This white paper outlines the operating principle, system architecture, economic efficiency, and regulatory classification of SHC and provides a balanced comparison of the technology with conventional compression refrigeration.

2. Background: Heat in the Production Hall as an Underestimated Operational Risk

In many manufacturing facilities, hall temperature has remained a secondary concern for decades, taking a back seat to machine availability, throughput, and quality assurance. However, with increasingly hot summers and the simultaneous rise in internal heat loads due to denser machine layout and automation, the hall climate is coming into sharper focus. Hall temperatures well above 30 degrees Celsius are not uncommon in non-air-conditioned or inadequately air-conditioned production facilities during the summer months.

The relationship between room temperature and work performance has long been documented in occupational science: As temperatures rise above the thermal comfort zone, the ability to concentrate and resistance to errors decrease, while fatigue and illness-related absences increase. For companies with high quality standards — such as those in precision manufacturing, the automotive supply industry, or food production — a stable indoor climate is therefore not just a matter of comfort, but a key factor affecting productivity and error rates.

Added to this are regulatory and business pressures: Reporting requirements under the Corporate Sustainability Reporting Directive (CSRD), as well as the internal climate targets of many industrial conglomerates, increasingly require suppliers and their own facilities to provide transparent reduction pathways for energy consumption and greenhouse gas emissions. Climate control for production facilities ranging from several thousand to tens of thousands of square meters is one of the major levers in a production site's energy budget.

Traditional compression refrigeration, as used in chilled water units or split air conditioning systems, faces several limitations when it comes to this task. Electricity consumption for generating cooling via a compression cycle is significantly higher than with water-based methods, which has a direct impact on operating costs and the carbon footprint. The refrigerants used are subject to the European F-Gas Regulation, which provides for progressively stricter limits and bans on substances with high global warming potential, thereby reducing the availability of replacement parts and planning certainty for existing systems. Maintenance costs and the service life of compressor systems also entail recurring expenses. Finally, in many retrofit projects, air conditioning continues to be planned as an isolated, standalone system, separate from ventilation, heat recovery, and the actual production process, which leaves potential synergies untapped.

This situation does not apply only to new construction projects. A significant portion of Europe's industrial space was built decades ago, when extreme summer temperatures of this frequency were not factored into the planning process. Consequently, many operators are faced with the question of how to replace an existing, often technically outdated cooling or ventilation system as part of an already planned renovation without interrupting ongoing production operations for an extended period. At the same time, the situation in the labor market is becoming more challenging: In regions with a shortage of skilled workers, the indoor climate is increasingly seen as a location factor for recruiting and retaining employees, particularly in physically demanding areas of production.

From an energy management perspective, too, the landscape is changing. Volatile electricity and gas prices in recent years have prompted many industrial companies to factor energy costs more heavily into their site planning than before. An air-conditioning concept that provides the majority of the required cooling capacity not through an electricity-intensive compression cycle but via a water-based process thus directly alters a facility's cost structure and its dependence on short-term price fluctuations in the electricity market.

3. Operating Principle of Two-Stage Adiabatic Cooling

3.1 Basic Physical Principle: Adiabatic and Evaporative Cooling

Adiabatic cooling utilizes a physical effect also known as evaporative cooling: When water evaporates, it extracts the enthalpy of evaporation required for this process from the surrounding air in the form of heat. The air temperature drops, while the absolute humidity rises, as the evaporated water remains in the air as water vapor. The process occurs without mechanical refrigeration and essentially requires only electrical energy for air and water transport, not for a compression cycle.

This basic principle is technically simple and resource-efficient; however, in its single-stage form, it presents a physically inherent trade-off: The more cooling that is to be achieved through evaporation, the more the relative humidity increases at the same time. Beyond a certain point, the air in the hall does become cooler, but at the same time noticeably more humid, which is subjectively perceived as muggy or uncomfortable.

3.2 Why Single-Stage Systems Reach Their Limits in Terms of Humidity

This relationship can be illustrated using a calculation example that corresponds to typical outdoor air conditions during a Central European summer: an outdoor temperature of 32 degrees Celsius with 25 percent relative humidity.

With single-stage adiabatic cooling, these conditions result in an indoor air condition of approximately 28.5 degrees Celsius with an absolute humidity of about 13.0 grams of water per kilogram of air. According to the comfort criteria of the EN-16798 and ASHRAE 55 standards, this combination of temperature and humidity falls outside the range defined as comfortable.

With the two-stage process used in SHC, the same outdoor conditions result in a hall air condition of approximately 24.5 degrees Celsius with about 11.6 grams of water per kilogram of air — a combination that falls within the comfort limits specified by EN-16798 and ASHRAE 55. At this point, it is important to distinguish between indoor air conditions and supply air temperature: The values mentioned describe the resulting indoor climate after the supplied air has mixed with the existing indoor air, not the temperature immediately at the outlet of the air conditioning unit.

The example shows that the second cooling stage not only brings about an additional temperature reduction but also limits the rise in humidity that would be unavoidable with purely single-stage evaporative cooling.

3.3 The Two-Stage Process in Detail

The two-stage process combines two different physical mechanisms. In the first stage, indirect, dry pre-cooling takes place: The outside air is passed through a heat exchanger connected to a separate water circuit that has been pre-cooled by evaporation. Since the air to be conditioned does not come into direct contact with the evaporating water, its temperature drops without an increase in humidity.

The second stage involves direct adiabatic cooling: The pre-cooled air is passed over a cooling honeycomb, where water evaporates and comes into direct contact with the air stream. Since the air is already cooler and drier than the original outdoor air at this point, the increase in humidity in this second stage is less than it would be with direct single-stage cooling starting from the original outdoor air.

On the Mollier diagram, which plots temperature against the moisture content of humid air, this process can be represented as a two-part path: a first, nearly horizontal section with decreasing temperature at constant absolute humidity, followed by a second section that runs along the evaporation line to a lower temperature with a moderate increase in humidity. The result is thus closer to — or even within — the comfort zone than the direct, single-stage process.

3.4 Technological Basis: The Adiabatic Cooling Honeycomb

The core component of both cooling stages is a patented, antibacterially coated aluminum cooling honeycomb. Evaporation occurs without pressure through contact evaporation on the surface of the honeycomb structure, not through the trickling or spraying of water into the airflow. This difference is technically significant, as it prevents droplet formation and the release of aerosols into the airflow — a point that is also relevant for regulatory classification in Chapter 6.

3.5 Hybrid Cooling: No Fundamental Temperature or Humidity Limits

Compared to single-stage systems, the two-stage adiabatic cooling described in Sections 3.2 and 3.3 is not physically limited by the wet-bulb temperature of the outside air: it can even cool below this wet-bulb temperature, but is limited by the wet-bulb temperature of the outside air that has already been pre-cooled to a dry state after Stage 1. For applications with particularly low target values for temperature or humidity that cannot be reliably achieved even with the two-stage adiabatic process, SHC can be expanded to include a mechanical cooling stage. In this variant, known as SHC-Hybrid, a comparatively small heat pump or chiller is connected downstream of the two-stage adiabatic cooling system. This allows even exceptionally demanding temperature or humidity setpoints to be achieved in an energy-efficient and resource-conserving manner, without having to rely entirely on a conventional compression refrigeration system.

Since the upstream two-stage adiabatic cooling already covers the majority of the cooling load, the downstream mechanical stage need only provide the remaining difference to the target value. In practice, the savings in CO_2 emissions and energy costs compared to a purely compression-based solution are typically still around 60 percent or higher even with SHC-Hybrid, depending on the project and target values. Since the mechanical refrigeration system need only be designed for the residual load, it is typically about 60 to 80 percent smaller in practice than a compression refrigeration system designed for the same total capacity. This reduces both the capital costs and the required refrigerant charge, which is particularly relevant in light of the regulatory developments regarding F-gases described in Chapter 6.

SHC-Hybrid is particularly well-suited for modern new buildings where the cooling capacity is significantly higher than the heating capacity for much of the year. In traditional designs, a reversible heat pump is often used in this scenario; it is designed for the high cooling load and, as a result, is oversized and thus operates inefficiently in heating mode. With SHC-Hybrid, adiabatic cooling handles the cooling load instead, while the heat pump need only be sized for the actual heating capacity — which has already been reduced by the SHC system's warm air recirculation described in Chapter 5. If necessary, cooling can also be supplemented on an as-needed basis by the heat pump's cooling capacity, for example on days with particularly challenging weather conditions and peak loads.

4. System Architecture: Modular System Instead of Individual Trades

SHC is designed as a modular system that goes beyond simple cooling. Available modules include cooling, heating, ventilation, indoor air purification, heat recovery, precision air conditioning, pre-cooling, and the retrofitting of existing systems as part of retrofit projects. The modules can be used individually for defined zones or combined to provide full-hall climate control for large, contiguous production areas.

Whether heat recovery makes technical sense in a specific project depends on the particular application. If the required air volume is determined primarily by the cooling load rather than by a minimum fresh air requirement dictated by ventilation needs, or if there is already a heat surplus in the facility that can be used to precondition the fresh air, additional heat recovery is not always necessary. In other cases, the system can be supplemented with a dedicated heat recovery module.

At INFRANORM®, the planning approach behind the system architecture is referred to as INFRANOMIC Engineering: The starting point for planning is not the building envelope, but rather the value-added process of the respective production facility. Cooling, heating, ventilation, and heat recovery requirements are considered collectively, rather than being specified and planned as separate systems independently of one another. This integrated approach is designed to harness synergies between the individual subsystems that would otherwise remain untapped if the individual systems were considered in isolation — for example, when waste heat from one production area is used to precondition fresh air in another area.

The retrofit module is particularly relevant for existing facilities. Instead of completely replacing an existing compression refrigeration system, SHC can in many cases be integrated into existing ventilation and building management systems in such a way that existing ductwork, media distribution, and control infrastructure can be reused, at least in part. The specific feasibility depends on the building's structure, the available roof area, and the existing building systems, and is assessed on a project-by-project basis.

The scalability of the modular system also allows for phased implementation. Instead of retrofitting an entire hall in a single construction phase, individual zones can be equipped on a priority basis — such as areas with particularly high internal heat loads or particularly high-quality requirements for the indoor climate — while other sections of the hall follow in later phases. This approach can help spread investment costs over time and incorporate lessons learned from an initial construction phase into the planning of subsequent phases, as was the case, for example, with the multi-phase project at BRP-Rotax in Gunskirchen, which is described in detail in Chapter 7.

5. Comparison of Energy and Resource Efficiency

The key efficiency advantage of SHC over conventional compression refrigeration stems from the fact that the entire cooling capacity is generated through the evaporation of water rather than through an electrically driven compression cycle. Depending on the project, climate zone, and system configuration, this results in up to 95 percent lower energy costs and CO_2 emissions for cooling compared to a comparable compression refrigeration solution. For systems with integrated heat recovery or heating, heating costs are reduced by up to 40 percent, as waste heat from production or from the cooling process itself is used to precondition the supply air in winter, and targeted de-stratification of the facility is achieved through warm air recirculation. These ranges are project-dependent and do not represent guaranteed values for every individual case, but rather serve as a guide based on systems that have been implemented.

One aspect that is often overlooked in the public debate on evaporative cooling methods is the actual total water consumption compared to electrically powered compression refrigeration. Although an adiabatic system evaporates water directly on-site, a conventional chiller itself indirectly requires considerable amounts of water, since a significant portion of the European electricity mix is generated in thermal power plants, which in turn rely on cooling water. For an identical cooling capacity of 90 kilowatts of sensible cooling, the following comparison emerges:

	Compression refrigeration (chiller)	**Two-stage adiabatic system (SHC)**
Electric power consumption	approx. 30 kW/h	approx. 1 kW/h
Cooling water demand at the power plant (supra-regional, across the electricity mix)	approx. 300 L/h	approx. 10 L/h
On-site water evaporation	–	approx. 90 L/h
Total water demand	approx. 300 L/h	approx. 100 L/h

The chiller’s electricity demand, which is 30 times higher, results in a supraregional water demand via power plant cooling that significantly exceeds the direct on-site consumption of the adiabatic system, despite visible local evaporation. In the overall balance, which includes the water consumption associated with electricity procurement, the total water demand of the two-stage adiabatic system is thus lower than that of compression refrigeration.

6. Regulations and Hygiene

In the public and regulatory perception, evaporative cooling processes are often associated with Legionella risks, such as those known from conventional cooling towers with water trickling or spraying. In Germany, such systems are subject to the 42nd Ordinance Implementing the Federal Immission Control Act (42nd BImSchV) as well as VDI Guideline 2047, which, among other things, regulate operator obligations, inspection intervals, and reporting requirements.

The cooling honeycomb technology used in SHC does not fall within the scope of application of § 1(3) of the 42nd BImSchV, as the ordinance expressly covers only systems with water trickling or water spraying. Since evaporation at the cooling honeycomb occurs without pressure via contact evaporation and no droplet formation or aerosol release takes place in the air stream, the process differs technically from the types of systems for which the regulation was designed. For the same reason, VDI 2047 — the so-called cooling tower regulation — does not apply either. Regardless, SHC is designed to comply with the relevant air quality regulations — VDI 6022, VDI 3803, and the Swiss standard SWKI VA104-01 — which generally govern requirements for ventilation and air-conditioning systems.

In the context of European refrigerant regulations, it is also relevant that SHC operates without the use of fluorinated greenhouse gases (F-gases) or refrigerants containing PFAS. The EU F-Gas Regulation provides for a phased reduction in the quantities of fluorinated refrigerants available in the European Union, with implications for spare parts availability, operating costs, and long-term planning certainty for existing compression refrigeration systems. A water-based process is not affected by this regulatory development to the same extent.

In practical terms, the elimination of F-gases and PFAS also means that operators are not affected to the same extent by recurring leak tests, reporting requirements, and the increasingly limited availability of certain types of refrigerants, as is mandated for existing systems using conventional refrigerants. Another factor relevant to daily operational safety is that the cooling honeycomb is designed for a daily complete drying phase, combined with continuous monitoring of water conductivity and an automated cleaning program. This combination of material selection, operational management, and monitoring forms the technical basis for ensuring that the process remains hygienically controllable despite the use of water as a cooling medium, without requiring the operational obligations typical of cooling towers.

7. BRP-Rotax Case Study, Gunskirchen

At the BRP-Rotax site in Gunskirchen, Upper Austria, a production area of 14,100 square meters was equipped with SHC during the first expansion phase. The system comprises 30 adiabatic coolers, each with an airflow rate of approximately 14,000 cubic meters per hour and a cooling capacity of approximately 90 kilowatts for fresh air or approximately 50 kilowatts for hall cooling. As part of the project, three existing ventilation units that previously lacked a cooling function were retrofitted accordingly; in addition, 20 exhaust fans and 12 ventilation units were newly installed.

During normal operation, the average power consumption for the entire production facility — including cooling, ventilation, and heating via 26 chillers — is approximately 51 kilowatts. Based on a single unit with an airflow rate of 14,000 cubic meters per hour, this results in a power consumption of approximately 2 kilowatts, which, when extrapolated, corresponds to an annual consumption of about 17,500 kilowatt-hours per unit. Regarding water consumption, a total of 2,770 cubic meters was recorded from June through March — a period of ten months — equivalent to approximately 107 cubic meters per cooler; extrapolated to a full year, this results in a range of about 140 to 160 cubic meters per cooler.

With the second phase of expansion, the entire production hall was subsequently equipped with SHC. A total of 650,000 cubic meters of fresh air per hour removes a thermal load of approximately 1.6 megawatts from the hall. In addition, the SHC system was expanded to include a fully integrated heating function for production downtime as well as hall air filtration for the winter months. As a result, the SHC system is the only comprehensive system in the entire production hall that ensures comfort, stable temperature and humidity conditions, and good air quality year-round.

Compared to the well water-cooling system previously operated at the site — or the well water heat pump that was an alternative option during the plant renovation — this project yields the following annual savings: approximately 250 metric tons of CO_2, 1.2 gigawatt-hours of electricity, and 250,000 cubic meters of well water. As part of the project, the site also switched from a gas boiler to district heating, resulting in additional savings of approximately 1,500 metric tons of CO_2 per year. These figures relate specifically to the BRP-Rotax project and cannot be directly applied to other sites with different initial conditions.

8. Brief Overview of Additional Reference Projects

The following data are derived from individual, completed projects and are presented as such, not as universally applicable metrics.

The projects at Senoplast and Palfinger in Niš, Serbia, are both new construction projects. Accordingly, the basis for comparison there was not a previous system, but rather the alternative compression refrigeration or heat pump solutions that were under consideration.

Compared to this alternative, the project implemented at Senoplast resulted in 82 percent lower CO_2 emissions and 80 percent lower cooling costs. The concept is being rolled out to another location in Mexico.

At Palfinger's site in Niš, energy consumption was reduced by 81 percent and CO_2 emissions by 90 percent compared to the compression refrigeration or heat pump solution that was available as an alternative there.

At NEUMAN Aluminium, the project succeeded in maintaining the hall temperature below 25 degrees Celsius even when the outside temperature was 36.7 degrees Celsius.

These three project results illustrate the range of achievable values across different industries and initial conditions; however, they do not replace project-specific design and simulation for a new site.

9. Cost-Effectiveness

In practice, the payback period for retrofit projects ranges from about six months to three years. The actual payback period depends largely on the initial conditions, particularly whether an existing cooling or heating system — which is already in need of renovation — is being replaced, how high the current energy prices are at the site, and how intensively the facility is used.

Reliable cost estimates can only be provided on a project-specific basis, as the hall's geometry, cooling load, existing building systems, and regional connection requirements significantly influence the investment amount. A blanket cost estimate without reference to a specific project would suggest a level of accuracy that does not exist at this stage.

For new installations, there is a difference compared to retrofit situations: For the same cooling capacity, the initial investment cost for SHC is generally already lower than that of a comparably sized compression refrigeration system, regardless of the operating energy costs described in Chapter 5. In this case, the economic advantage is therefore not limited to operating costs over the system's service life but is already evident in comparison of investment costs at the time of installation.

Before a system is installed, the expected performance values are simulated based on real building data and local weather station data. This preliminary simulation serves to determine project-specific guaranteed values for temperature and humidity profiles as well as for expected energy consumption before an investment decision is made. These simulations are based, among other things, on 132 projects completed in recent years, which received an average customer satisfaction rating of 9.26 out of 10 points.

For the economic evaluation, the timing of the investment is relevant in addition to the pure payback period. If a replacement investment for an existing, technically obsolete cooling or heating system is already due, the comparative analysis differs fundamentally from that of a new investment in a system that is still functional, since in this case it is not the full investment costs but only the difference from a replacement purchase that would have been necessary anyway that needs to be evaluated economically. This effect is also exemplified in the BRP-Rotax project from Chapter 7, in which the conversion took place as part of a renewal of the existing plant technology that was necessary anyway. In addition to the direct energy cost savings, indirect economic effects may arise, such as lower maintenance costs resulting from the elimination of compressors and refrigerant circuits, as well as a potential reduction in production-related downtime attributable to inadequate climate control. However, a reliable quantification of these indirect effects is only possible on a case-by-case basis using the respective operating data and is not reported on a blanket basis.

10. Market Comparison

In a direct comparison with conventional compression-based refrigeration heat pump technology, the two approaches differ significantly in several technical and economic criteria.

Criterion	**Compression-based heat pump**	**Sustainable Hall Conditioning**
Refrigerant	F-gases required; subject to increasing regulatory restrictions	No use of F-gases or PFAS
Electricity consumption	Comparatively high (compression cycle)	Significantly lower
CO_2 footprint	Depends on the electricity mix; tends to be higher	significantly lower
Noise emissions	Compressors and fans as sources of noise	Lower noise emissions due to the elimination of compressors
Capital and operating costs	Established pricing structure, ongoing refrigerant and maintenance costs	For new systems with equivalent performance, investment costs are generally lower from the outset; additionally, depending on the project, operating costs are lower over the system's service life
Roof structural integrity	Chillers and recoolers, some of which are quite heavy	Generally lower structural load
System complexity	An established, self-contained individual trade	Integrated planning across multiple trades, requiring greater coordination during the planning phase, but resulting in a synergistic overall system
Market maturity and system experience	Established for many years, broad base of market experience	A newer but established and innovative technology with a rapidly growing project portfolio

In the vast majority of the criteria considered, SHC demonstrates clear advantages over conventional compression refrigeration, particularly in terms of refrigerant use, electricity consumption, carbon footprint, and noise emissions. Even in terms of system complexity, the greater coordination effort required during the planning phase is offset by a synergistic integrated system that combines cooling, ventilation, heating, and heat recovery rather than treating them as separate systems. Only in terms of market maturity does conventional compression refrigeration have the longer history and broader experience base among manufacturers, planners, and operators; in contrast, SHC has positioned itself on the market in recent years as an innovative, increasingly established technology with a rapidly growing project portfolio. With regard to potential operational disruptions during the implementation phase, the two systems do not differ fundamentally from one another.

Against this backdrop, SHC can be classified as a technically and economically viable alternative to conventional compression refrigeration, particularly for new installations as well as for the retrofitting of technically obsolete existing systems. However, a blanket recommendation for every application is not appropriate given the project- and climate-dependent factors: As described in the following paragraph, actual suitability depends on the respective climate zone, the type of facility, and the internal heat load profile, and should be evaluated on a case-by-case, project-specific basis.

For the evaluation of individual cases, it is important to note that the comparison above reflects general trends, the impact of which can vary depending on the climate zone, hall type, and internal heat load profile. In regions with high humidity during the summer months, for example, the achievable cooling capacity of an adiabatic system is physically more limited than in dry climate zones, since the efficiency of evaporative cooling depends on the difference between air temperature and wet-bulb temperature. Conversely, locations with high cooling demands year-round and simultaneously high fresh air requirements — such as in food production or paint shops — tend to benefit more from an integrated approach combining cooling, ventilation, and heat recovery. It is therefore not possible to make a blanket statement about which of the two methods is economically and technically preferable for a specific location without a project-specific analysis; the preliminary simulation described in Chapter 9, based on real site and weather data, serves precisely this purpose.

11. Conclusion and Outlook

Sustainable Hall Conditioning represents a technically sound alternative approach to conventional compression refrigeration for the climate control of production halls. The two-stage adiabatic cooling resolves the physically inherent trade-off in single-stage evaporative cooling between temperature reduction and humidity increase, thereby achieving indoor air conditions within recognized comfort limits. Completed projects such as BRP-Rotax, Senoplast, Palfinger, and NEUMAN Aluminium demonstrate the magnitude by which energy consumption, CO_2 emissions, and — when considering the total water footprint — water consumption can be reduced, although the specific values vary by project.

Against the backdrop of rising energy costs, foreseeable stricter regulations on fluorinated refrigerants, and increasing ESG reporting requirements for manufacturing companies, the importance of resource-efficient climate control concepts for production facilities is likely to continue to grow in the coming years. For facility managers, planners, and energy officers facing the decision to install a new system or retrofit an existing refrigeration system, a project-specific assessment of the facility's climate and the alternatives available to conventional compression refrigeration can provide a sound basis for decision-making.

About INFRANORM® Technologie GmbH

INFRANORM® Technologie GmbH is an Austrian company founded in 2004 and headquartered in Wels, Upper Austria, that serves manufacturing companies throughout Europe. The company's planning approach, INFRANOMIC® Engineering, is based on the customer's value-creation process and designs production infrastructure in an integrated manner rather than as separate trades. Over the course of its 22-year history, the company has completed more than 950 projects. Awards include the Energy Globe Award (winner in 2020, nominee in 2024), the Pegasus Business Award 2025 (Bronze), the ALC Award 2025 (2nd place in Upper Austria), a nomination for the Feronia Sustainability Award 2025, and several environmental management awards.

Source note: The figures, project data, and case studies cited in this white paper are based on internal project data from INFRANORM® Technologie GmbH as well as manufacturer documentation, as of 2026.