Guidelines for Simulation Tools and Monitoring the Performance of SHIP Systems

IEA SHC TASK 64 | IEA SolarPACES Task 4 | Solar Process Heat

Technology Collaboration Programme
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Guidelines for Simulation Tools and Monitoring the Performance of SHIP Systems

This is a report from SHC Task 64 / SolarPACES Task IV: Solar Process Heat and work performed in Subtask C: Simulation and Design Tools

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Solar Heating and Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *To bring the latest solar heating and cooling research and information to the forefront of the global energy transition.*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

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- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64, 72)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, Test Methods and LCA/LCoH (Tasks 14, 24, 34, 43, 57, 71)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
- SHC International Conference

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To carry out this mission, SolarPACES coordinates and advances concentrating solar technology researchby focusing on the next generation of technologies, by providing information and recommendations to policy makers and by organizing international conferences, workshops, reports, and task meetings.

Our focus areas are organized in six tasks:

- Task I: Solar Thermal Electric Systems
- Task II: Solar Chemistry Research
- Task III: Solar Technology and Advanced Applications
- Task IV: Solar Heat Integration in Industrial Processes
- Task V: Solar Resource for High Penetration and Large Scale Applications
- Task VI: Solar Energy and Water Processes and Applications

In addition to our Task work, other activities of the IEA SolarPACES include:

- SolarPACES International Conference.
- Review of CSP market and cost data with the International Renewable Energy Agency (IRENA).
- Joint project on solar resource for high penetration and large scale applications in collaboration with the TCP on Photovoltaic Power Systems (PVPS TCP).
- Project in solar process heat in collaboration with the TCP on Solar Heating and Cooling (SHC TCP).

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Contents

1 Introduction to the Methodological Analysis of Solar Thermal Plant Technologies

The integration of solar thermal technologies into the industrial sector represents a significant move toward sustainable energy utilization. This report presents a comprehensive analysis of various methodologies regarding the design, implementation, and operational management of solar thermal plants. The focus of this analysis encompasses a broad spectrum of approaches that are fundamental to optimizing the efficiency and effectiveness of these renewable energy systems. This document presents the most significant outcomes of the second stage of Subtask C: Simulation and Design Tools, specifically Task 64/IV, jointly developed under the framework of the International Energy Agency's Solar Heating and Cooling Programme and SolarPACES. Throughout the four-year execution of the Task, Subtask C brought together 50 participants from academia, applied research, and project developers from 15 countries. The combination of state-of-the-art research, existing technical documentation, and on-the-ground experience of project developers adds value to the outcomes of this analysis.

Central to this investigation is the examination of design strategies that prioritize not only technical efficiency, but also environmental and economic sustainability. This involves a nuanced understanding of the interplay between solar thermal technology and industrial processes, ensuring that the implementation of these systems aligns with specific industrial needs while maximizing energy harnessing. An integral aspect of this analysis is the exploration of performance measurement and verification techniques. The precision and accuracy of these methods is paramount for evaluating the efficacy of solar thermal plants. Thus, by scrutinizing various measurement strategies, the report seeks to highlight the importance of rigorous performance assessments in maintaining high operational standards.

Furthermore, the report examines the role of advanced sensor technologies and monitoring systems in enhancing the functionality and reliability of solar thermal plants. These technologies are crucial in providing real-time data and insights, facilitating proactive maintenance and enabling data-driven decision-making processes. The report delves into the selection criteria, deployment tactics, and analytical applications of these sensor systems, underscoring their significance in the overall management of solar thermal installations. Additionally, the report addresses the challenges and solutions associated with the maintenance and scalability of large-scale solar thermal systems. It presents an overview of best practices and innovative approaches to maintaining system integrity, efficiency, and adaptability in the face of evolving industrial demands and environmental conditions. In conclusion, this analysis aims to merge various methodological insights into a cohesive framework, thereby providing a comprehensive guide for stakeholders in the solar thermal industry. The objective is to foster a deeper understanding of these systems, contributing to the ongoing efforts to enhance the efficiency, sustainability, and integration of solar thermal technologies in the industrial sector.

This document is structured as follows: firstly, it presents a comparative summary of reference documents regarding the operation and monitoring of solar thermal plants. Secondly, it indicates key aspects to be considered during the design phase as well as in the operation and maintenance phase, including which variables to measure, where to measure, what sensor to use, etc. Additionally, specific aspects for the main solar process heat technologies are outlined, considering critical components and environmental conditions. Moreover, the report outlines the main topics that should be taken into account during monitoring and maintenance according to recommendations from companies developing projects for industrial process solar heat and companies monitoring solar systems to optimize their usage. Finally, the document presents the conclusions of the work carried out in Subtask C regarding Best Practices in monitoring and maintenance of SHIP plants.

2 Comparative Analysis of the Documents

Since the formulation of the contents of Task 64 in 2019, certain documents have been published to assist SHIP systems developers and clients in guiding the design for proper operation and maintenance, such as standards aimed at minimizing measurement uncertainties, as well as guidelines on how to approach performance monitoring systems to optimize the costs and benefits of solar systems. The following table summarizes the key methodologies and approaches presented in each of the documents:

Table 1. Key methodologies and approaches

DOCUMENT	DESIGN FOCUS	MONITORING AND MEASUREMENT	MAINTENANCE FOCUS	ADDITIONAL CONSIDERATIONS
PROCESOL II – DESIGN AND MAINTENANCE GUIDELINES	Optimization of industrial process, plant configurations and combinations	Low-cost maintenance, periodic inspections, remote monitoring	Correct design and installation to minimize maintenance	Periodic controls and efficient monitoring
ISO-FDIS 24194-2022(E) – PERFORMANCE VERIFICATION	Specification of two procedures: how to compare a measured output with a calculated one.	Verification of thermal power and daily performance, precise measurement	N/A	Accuracy and location of sensors, cleaning and maintenance of solar sensors
SPECIFIC SENSORS FOR GLOBAL EVALUATION	Selection and installation of sensors for precise measurement	Measurement of temperature, flow, direct and concentrated solar irradiation; use of infrared technology	N/A	Characterization of reflective and absorptive surfaces
UNEP – LARGE-SCALE SOLAR THERMAL SYSTEMS	From simple thermosyphon systems to more complex forced circulation systems	Heat production measurement, fault detection, remote monitoring	Performance optimization, possibility of controller expansion	Costs and benefits of monitoring, performance-based business models

Key Observations:

- Diversity in Design Approaches: While some documents, like PROCESOL II and Specific Sensors, focus on optimizing the design and selecting components, others do not address this aspect directly.
- Monitoring and Measurement: There is a common emphasis on the importance of monitoring and precise measurement, even though the methods and technologies used vary.
- Maintenance Focus: Efficiency in maintenance and early problem detection are recurring themes, with different approaches depending on the type and size of the solar thermal system.
- Additional Considerations: Operational efficiency, data security, and the economic aspects of monitoring and operation are considered in several documents, highlighting the complexity of managing solar thermal plants.

The table provides an overview that allows for the comparison and contrast of different methodologies and approaches in the documents.

3 Comparative Analysis of Methodologies in the Documents

Differences in Equipment and Sensors and their Usage Methodologies

1. PROCESOL II – Design and Maintenance Guidelines:

    - Does not specifically detail types of sensors or equipment used.
    - Focuses on general design and maintenance rather than on specific sensor details.

2. ISO-FDIS 24194-2022(E) – Performance Verification:

    - This report points out the need for precise instrumentation to measure solar radiation, temperature, and flow.
    - It includes details of the sensors' locations for different system layouts (example in Figure 1)
    - It focuses on measurement accuracy for performance verification, suggesting precision levels for different sensors.

3. Specific Sensors for Global Evaluation:

    - This report details a variety of specific sensors, including thermocouples, resistance thermometers, ultrasonic or Vortex flow meters, pyrheliometers, and Gardon-type sensors.
    - The methodology involves precise measurements at specific points, such as the solar field's inlet and outlet and measuring direct and concentrated solar irradiation.

4. UNEP – Large-Scale Solar Thermal Systems:

    - This report refers to solar thermal controllers and temperature sensors for forced circulation systems.
    - It also refers to heat production measurement using heat meters or controllers with temperature sensors.

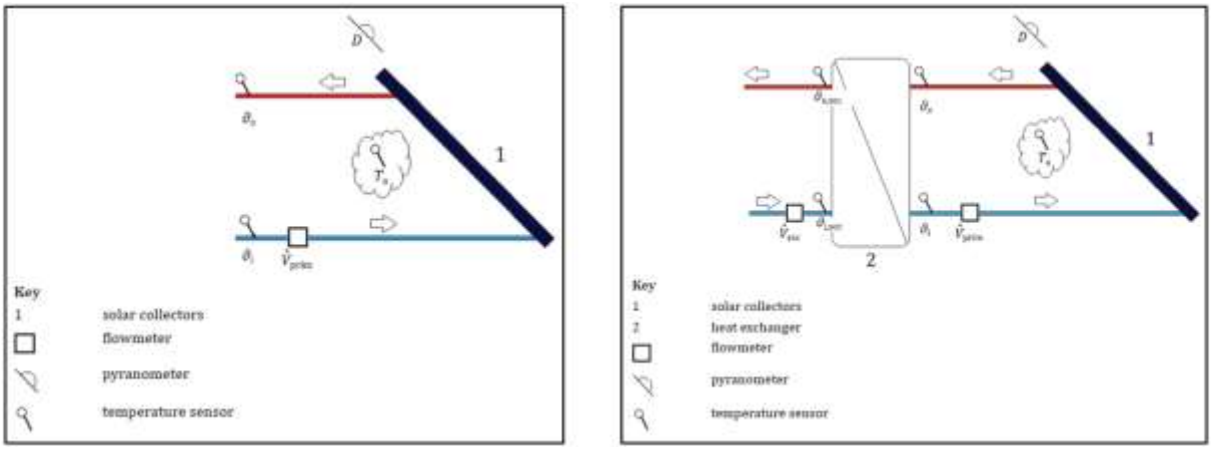

Figure 1. Sensors for a collector system with and without HX. It can be observed that including a HX requires doubling the number of sensors, i.e., from 1 flow meter + 2 temperature sensors to 2 flow meters + 4 temperature sensors.

3.1 Comparison and Contrast of Equipment and Sensor Usage Methodologies

The following points compare and contrast key methodological aspects identified in the documents:

- Focus on precision: both ISO-FDIS 24194-2022(E) and "Specific Sensors for Global Evaluation" emphasize the importance of precise measurements, using specific sensors and equipment designed to gather accurate data. This contrasts with the more general approach of PROCESOL II, which does not specify sensor types.
- Diversity of sensors: "Specific Sensors for Global Evaluation" provide a wider range of sensor types, covering a variety of measurements like temperature, flow, and solar radiation. This is more specific compared to the more general description of monitoring equipment in the UNEP document.
- Simplification vs. detail: while the "Summary of Implementation and Monitoring Meetings" emphasizes simplification in sensor use for commercial plants, the ISO document and "Specific Sensors" lean towards a more detailed and technical approach, suitable for R&D applications and performance verification.
- Practical application vs. research and development: there is a clear distinction between approaches used in practical commercial settings (as pointed out in the "Summary of Meetings") and those used in R&D environments or for performance verification (as in the ISO-FDIS 24194-2022(E) and "Specific Sensors"). The former tend to prioritize efficiency and simplicity, while the latter focus on precision and detail.

These differences reflect the variety of needs and approaches in the field of solar thermal plants, from research and development to commercial implementation and operation. The choice of sensors and equipment is influenced by the specific goal of each project, whether it is optimizing performance, verifying efficiency, or efficiently and profitably managing large-scale systems.

4 Key aspects in monitoring and measurement of flat-plate, Fresnel, and parabolic through collectors for Process Heat Generation

4.1 Common aspects in monitoring and measurement:

Energy Efficiency and Performance: it is the ratio between the thermal energy collected by each collector and the incident solar radiation. Common for all technologies, the collector loop efficiency can be determined as follows:

$$\eta_{th/col,loop} = \frac{\dot{Q}_{abs,loop}}{\dot{Q}_{inc,loop}} 100\ (\%) \tag{1}$$

where $\dot{Q}_{abs,loop}$ and $\dot{Q}_{inc,loop}$ represent the absorbed solar energy by each collector loop and the incident radiation on each collector loop. $\dot{Q}_{abs,loop}$ depends on the mass flow rate and the difference between the inlet and outlet temperatures of each loop, whereas $\dot{Q}_{inc,loop}$ depends on the aperture area and the incident radiation on the collector plane. Consequently, the overall thermal efficiency of the heat transferred to the industrial process can be determined as

$$\eta_{th/proc} = \frac{\dot{Q}_{abs,proc}}{\dot{Q}_{inc}} 100\% \tag{2}$$

where $\dot{Q}_{abs,proc}$ corresponds to the total thermal energy delivered for the industrial process side, and $\dot{Q}_{inc}$ is the total incident radiation on the solar field. Thus, the overall efficiency losses ($\eta_{ov,losses}$) from the solar system side can be determined by the following relationship:

$$\eta_{th/proc} = \eta_{th,SF}\,\eta_{ov,losses} \quad (3)$$

where $\eta_{th,SF}$ represents the total thermal performance of the collector field and $\eta_{th/col,loop}$ from Eq. (1). Moreover, the deviation of $\eta_{th/col,loop}$ and $\eta_{th/proc}$ from their design conditions can be determined as follows:

$$\Delta\eta_{th/col,loop} = \frac{|\eta_{th/col,loop} - \eta_{th/col,loop}|_{des}|}{\eta_{th/col,loop}|_{des}} 100\% \quad (4)$$

$$\Delta\eta_{th/proc} = \frac{|\eta_{th/proc} - \eta_{th/proc}|_{des}|}{\eta_{th/proc}|_{des}} \cdot 100\% \quad (5)$$

where $\eta_{th/col,loop}|_{des}$ and $\eta_{th/proc}|_{des}$ correspond to the design efficiencies of each loop and the overall thermal efficiency. It is worth noting that tolerances in terms of efficiency percentage point losses are a defining factor that may or may not exhibit global uniformity, as they depend on each O&M unit. However, this deviation under a steady-state condition should not exceed 10% to ensure the proper functioning of the plant.

1. Temperature Monitoring:

Tracking the temperature of the heat transfer fluid is needed to ensure it remains within an optimal range for efficient operation. This quantification can be carried out using the Temperature Deviation Index (TDI) of the heat transfer fluid with respect to the optimal temperature. It should be noted that this indicator can be used from both the industrial process side and the solar field side to monitor the deviation of the output temperature with respect to its set point.

$$TDI = \frac{T_{observed} - T_{set}}{T_{set}} \cdot 100\% \quad (6)$$

where $T_{observed}$ and T_{set} correspond to the observed temperature and the set-point of temperature, which is required by the process or at the output of each collector loop.

2. Pressure and Flow:

Similar to temperature, fluid pressure and mass flow can be quantified through the Pressure and Mass flow Deviation Indexes (PDI and MDI). PDI and MDI can be computed as follows:

$$PDI = \frac{P_{observed} - P_{set}}{P_{set}} \cdot 100\% \quad (7)$$

$$MDI = \frac{\dot{m}_{observed} - \dot{m}_{set}}{\dot{m}_{set}} \cdot 100\% \quad (8)$$

where $P_{observed}$ and $\dot{m}_{observed}$ correspond to the observed pressure and mass flow rate, respectively. Meanwhile, P_{set} and $\dot{m}_{set}$ are the optimal set-point of pressure and mass flow which are required by the process or at the output of each collector loop.

3. Structural Integrity:

The structural integrity of solar collectors stands as a linchpin in their functionality within industrial processes. Its role extends beyond mere stability, encompassing the assurance of efficiency, environmental resilience, and safety in industrial settings. Therefore, a proactive approach involving regular and rigorous assessments ensures early detection of structural problems, preventing further deterioration and minimizing extensive repairs. Therefore, this work proposes a Structural Integrity Assessment (SIA) scale which offers a standardized approach, independent of the technology integrated into the industrial process in question. Using the scale makes it possible to evaluate different collectors consistently, guaranteeing uniformity in the evaluation of the severity of structural problems. This quantification of qualitative aspects can be carried out as follows:

Table 2. Coefficients for the SIA.

LEVEL OF STRUCTURAL DAMAGE	
SCORE	**Description**
1	No visible damage
3	Minor or superficial damage
5	Moderate damage
8	Significant damage affecting structure
10	Severe damage compromising integrity
CORROSION LEVEL	
SCORE	**Description**
1	No signs of corrosion
3	Minor signs of corrosion
5	Moderate corrosion
8	Considerable corrosion affecting structure
10	Severe corrosion compromising integrity
WEAR AND TEAR	
SCORE	**Description**
1	No visible signs of wear
3	Minor visible wear
5	Moderate visible wear
8	Significant wear impacting structure
10	Substantial wear or erosion
STRUCTURAL UNIFORMITY	
SCORE	**Description**
1	Uniform structure without deformations
3	Minor perceptible deformations
5	Some visible deformations
8	Deformations impacting integrity
10	Severe deformations compromising structure

This information can be collected physically and digitally as shown in Appendix 2, which facilitates an active monitoring of the plant’s integrity. The periodicity of the inspections must be defined by the units in charge of O&M so that it does not imply a detriment to the resources and work allocated by this unit.

4.2 Specific Aspects for Each Technology:

4.2.1 Critical aspects

1. **Flat Plate Collectors:**

   - **Uniform Heat Absorption:** The uniformity of heat absorption through the temperature distribution across the solar panel should be measured to ensure even heat distribution.
   - **Integrity:** Monitoring the integrity**,** cracks, and packing loss imply pressure losses and increased degradation resulting in loss of efficiency.

2. **Fresnel Collectors and Parabolic Through Collectors:**

   - **Solar Tracking:** The solar tracking system should be monitored to optimize solar radiation capture throughout the day.
   - **Reflector Precision:** The reflector's precision should be assessed to maximize the concentration of solar radiation onto the receiver.
   - **Integrity:** Monitoring the integrity, cracks, and packing loss imply pressure losses and increased degradation resulting in loss of efficiency.

4.2.2 Critical Considerations:

The aforementioned has implications for the following aspects of the operation:

1. **Maintenance:** Regular maintenance should be scheduled to prevent issues such as dirt accumulation, corrosion, or other factors that may affect efficiency.
2. **Reliability:** The reliability of control systems should be ensured and there must be backup protocols in case of failures.
3. **Safety:** Safety systems should be evaluated and maintained to prevent risks related to overheating or pressure.

4.2.2.1 Measurable Aspects for Proper Operation:

1. **Overall Efficiency:** The heat provided to the industrial process should be measured and compared to incident solar energy.
2. **Heat Transfer Fluid Temperature:** This temperature should be monitored to keep it within optimal operational ranges.
3. **Pressure and Flow:** These should be constantly verified to ensure consistent flow and appropriate pressure levels.
4. **Tracking and Control:** Solar tracking systems and control mechanisms should be tracked to optimize solar radiation capture.

Regular monitoring and measurement are essential to ensure optimal performance and extended longevity of solar collectors integrated into industrial processes for heat generation.

4.2.2.2 Determining Inspection Frequency:

The frequency of inspections for solar collectors is crucial for ensuring their operational reliability and longevity. Precision in setting inspection intervals relies on various factors:

- **Criticality of Components:** Daily inspections of critical components like pressure valves, fluid flow meters, and temperature controls are indispensable, as these components play a fundamental role in maintaining system safety and optimal performance.

- **Environmental Conditions:** Environmental factors significantly impact maintenance needs. In harsh environments susceptible to dust accumulation or corrosive elements, more frequent inspections—ideally on a weekly or bi-weekly basis—are imperative to prevent damage and uphold efficiency.

- **Manufacturer Recommendations:** Adhering to manufacturer-prescribed maintenance schedules outlined in equipment manuals is essential. These guidelines are tailored to ensure peak performance and extend the lifespan of the collectors.

- **Historical Performance Analysis:** The analysis of historical data helps to identify recurring issues or patterns at specific intervals. Adjusting inspection frequency based on past trends ensures proactive maintenance, mitigating potential problems before they escalate.

4.2.2.3 Critical Daily Inspections:

- **Pressure and Temperature Controls:** Daily checking of pressure and temperature controls is non-negotiable. Maintaining these parameters within specified ranges ensures operational safety and efficiency, preventing system failure or overheating.

- **Fluid Flow and Piping:** Daily inspections of fluid flow rates and piping connections are crucial. Any irregularities or blockages in the flow paths can impair heat transfer efficiency, impacting overall system performance.

- **Safety Systems:** Daily verification of safety systems, including emergency shutdown mechanisms, is paramount. Immediate actionability in case of anomalies or emergencies ensures the protection of personnel and equipment.

4.2.2.4 Predictive Maintenance Integration:

- **Vibration Analysis:** Integrating vibration analysis techniques helps predict potential failures in moving parts like tracking systems or pumps. Early detection allows for timely maintenance, preventing costly breakdowns and production halts.

- **Thermal Imaging:** Utilizing thermal imaging helps to detect irregular heat distribution across collector panels. Anomalies may indicate issues like inefficient absorbers or damaged reflectors, prompting targeted maintenance.

- **Performance Trend Analysis:** Regular analysis of performance trends helps to anticipate efficiency declines. Comparing the energy output against the sunlight received enables the identification of deviations, prompting proactive maintenance to sustain optimal performance.

- **Component Wear Monitoring:** Consistent monitoring of critical component wear, such as reflectors or absorbers, through routine inspections facilitates predictive maintenance planning. This approach allows for timely replacements or repairs, preventing operational disruptions.

5 Advice and experience from SHIP project developers and operators

The lessons learned from different key actors who participated in Subtask C were shared with all the participants during meetings. This shows that there is still a gap between design (pre-design, simulation, techno-economic analysis) and what is observed when actually building the system in a working industry. Beyond technical considerations, legal aspects, data storage and security, and interpretation of KPIs are of great importance. Appendix 1 indicates the details of the meetings held with the presenters and some key actions to take into account during the operation and maintenance of SHIP plants. The main observations are included here.

External monitoring companies are increasingly focused on delivering efficient solar heat rather than merely collecting data. Recognizing the niche of providing monitoring services to system owners, these companies emphasize the importance of avoiding costly sensors and offering different user access levels for control differentiation. By prioritizing efficient heat delivery, these companies aim to enhance the overall performance of solar systems, catering specifically to small-scale industries and residential clients.

From a developer's perspective, optimizing heat production and ensuring client satisfaction are paramount. Developers stress the need for simplified performance metrics and robust O&M contracts to maximize the lifetime productivity of industrial process plants. Developers underscore the significance of accurately defining target heat delivery during the design phase, leveraging certified heat meters for verification and adjusting targets based on energy measurements. Additionally, they advocate for proactive maintenance strategies to detect and rectify issues promptly, thus minimizing downtime and optimizing system performance.

Moreover, research and development institutes play a crucial role in advancing solar heat integration plants (SHIPs) through enhanced data acquisition and fault detection mechanisms. They emphasize the importance of increased sensor deployment for improved accuracy, especially given the challenges associated with temperature sensor precision. Leveraging advanced data acquisition techniques, R&D institutes strive to detect anomalies in system efficiency, such as overheating due to design miscalculations, enabling timely interventions to optimize SHIPs' performance and reliability.

6 Conclusions on Solar Thermal Plant Best Practices

The document encapsulates the main findings from the second stage of Subtask C: Simulation and Design Tools, part of Task 64/IV. Over the span of four years, Subtask C convened 50 participants representing academia, applied research, and project developers across 15 countries. The synthesis of cutting-edge research, extant technical literature, and firsthand insights from project developers enriches the significance of the analysis presented in this report.

The analysis of various methodologies in solar thermal plant management underscores the significance of integrating precise monitoring, diligent operation, and strategic control to enhance overall efficiency and sustainability. By meticulously tracking operational parameters and environmental conditions, stakeholders can make informed decisions, leading to significant improvements in system performance.

Proactive and predictive maintenance emerges as a key theme in ensuring the longevity and efficiency of solar thermal plants. Such foresight allows for timely interventions, reducing unplanned downtime and extending the lifespan of critical components. In an industry where operational interruptions can lead to substantial financial losses, the value of predictive maintenance cannot be overstated.

Operational optimization, another crucial aspect, entails the fine-tuning of solar thermal processes in response to real-time data. This dynamic approach to operation accounts for fluctuations in environmental conditions and energy demands, ensuring that the plant operates at its optimal capacity. Such adaptability not only enhances energy output but also contributes to the longevity of the plant by preventing overuse or strain on the system.

The integration of comprehensive renewable energy management systems stands out as a pivotal factor for centralized control and monitoring. These systems offer a unified platform for overseeing various aspects of plant operations, from energy production to maintenance scheduling. They facilitate not just the efficient operation of individual plants but also their seamless integration into the broader energy grid, an essential aspect for the widespread adoption of solar thermal energy.

Adherence to industry standards and best practices forms the bedrock of solar thermal plant management. This adherence ensures compliance with safety regulations, environmental norms, and performance benchmarks. It also involves staying abreast of advancements in solar thermal technology, including the latest research and development. This continuous learning and adaptation are crucial for maintaining the relevancy and efficiency of solar thermal plants in a rapidly evolving energy landscape.

In essence, the efficient management of solar thermal plants is a multifaceted endeavour that requires a balanced combination of advanced technology, strategic planning, and adherence to best practices. The insights derived from this analysis not only serve as a guideline for current operations, but also pave the way for future innovations and improvements in the field. As the world increasingly turns to renewable energy sources, the role of solar thermal plants in sustainable industrial processes becomes ever more significant, highlighting the need for ongoing research, development, and refinement of these technologies.

7 Appendix

7.1 Appendix 1

During the execution of the second stage of Subtask C, several discussions were held within participants' meetings. In addition, six representatives from the industry presented their experiences and lessons learned:

Table 3. Discussions meeting organized by Subtask C

	INDUSTRY REPRESENTATIVES
MEETING 1	SolarWave – Henry Vandermark Solatom – Miguel Frasquet
MEETING 2	Newheat - Alexis Gonnelle SPF - David Theiler
MEETING 3	Modulo Solar - Daniel García Glasspoint - Gerhard Weinrebe and Klaus-Jürgen Riffelmann

Certain important aspects, based on their experience dealing with the operation department of the different clients, can be summarized as follows:

- External monitoring focuses on efficient solar heat delivery rather than just on data collection, targeting owners for service provision.
- Developers prioritize simplified client-centric performance metrics and robust O&M contracts to maximize heat production over the plant's lifetime.
- O&M requirements impact business models, with contracts featuring bonuses and penalties indexed on thermal performance.

- Target solar heat delivery is set during design, verified using certified heat meters, and adjusted based on energy measurements.
- There is an emphasis on enhancing performance in both design and O&M phases, with real-time data monitoring and routine preventive maintenance.
- Each SHIP plant typically collects around 300 data points, with 50 transmitters per site, recording every second. These large data should be processed to become useful.
- R&D institutes utilize more sensors for enhanced data acquisition than industrial applications, with improved frequency from 10-minute to 1-second intervals.
- There are challenges in temperature sensor accuracy, particularly for small energy measurements, impacting heat measurement precision.
- Fault detection relies on efficiency measurements, detecting outliers like overheating due to design phase miscalculations.
- The integration of advanced software and database servers facilitates data management and analysis for improved system performance.

7.2 Appendix 2

Date: _______________	**Inspector:** _______________

Criterion	**Score (1-10)**
Level of Structural Damage	[Input Score]
Corrosion Level	[Input Score]
Wear and Tear	[Input Score]
Structural Uniformity	[Input Score]
Total Score: Total Score = (Score1 + Score2 + Score3 + Score4) / Total Number of Criteria Evaluated	[Calculated Total]

Comments/Remarks:

Unit Inspection Confirmation:	**Unit Stamp:**
Name: _______________	
Signature: ___________	
Date: _____________	