GreenWEC

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Executive summary

In an era marked by growing environmental concerns and the imperative to **conserve natural resources**, the agricultural sector faces increasing pressure to **innovate existing practices.** Water scarcity has become a critical challenge, particularly in water-intensive processes like greenhouse cultivation and breeding.

Traditional methods of managing greenhouse environmental conditions, such as natural or forced ventilation, mechanical refrigeration cycles, or pad and fan systems, are often inefficient and **resource intensive.** These methods can lead to uneven performances, inadequate humidity control, and **excessive energy and freshwater consumption.**

To address these challenges, our project focused on several critical areas:

1. Stakeholder Analysis and User Requirements: We conducted a comprehensive stakeholder analysis, including agricultural enterprises, governments, regulatory bodies, and more. Stakeholder requirements fell into four key categories: technical needs, human-based needs, business-related needs, and regulatory needs. Our goal is to create an **innovative and economically sustainable replacement for current cooling methods** that satisfies these diverse requirements.

2. State of the Art and Current Technology: We evaluated existing cooling technologies, with **Munters' patented CELdek as a benchmark.** While highly efficient, it consumes significant water and raises concerns about the durability and end-of-life management of paper-based pads. Other technologies, such as mechanical refrigeration cycles, absorption refrigeration cycles, and water harvesting, presented their own challenges and limitations.

3. Attributes for Optimal Direct Evaporative Cooling (DEC) Pad Performance: Our research **identified key attributes** for optimal DEC pad performance, including large water-to-air contact, low pressure drop, durability, and easy maintenance. We also **explored various materials**, highlighting the promise of vegetable fibers like jute and plastic materials like PVC and polyethylene for their durability, salt resistance, and sustainability.

4. Experimental Activities: Our team conducted extensive experimental activities to reduce freshwater usage and ensure compatibility with existing infrastructure. We focused on **materials that exhibited promising salt resistance and performance characteristics.** The process included artificial aging to simulate real-world conditions and performance testing. Our findings indicated that Nylon-based pads offer a potential alternative to current solutions, combining low salt deposition with excellent performance.

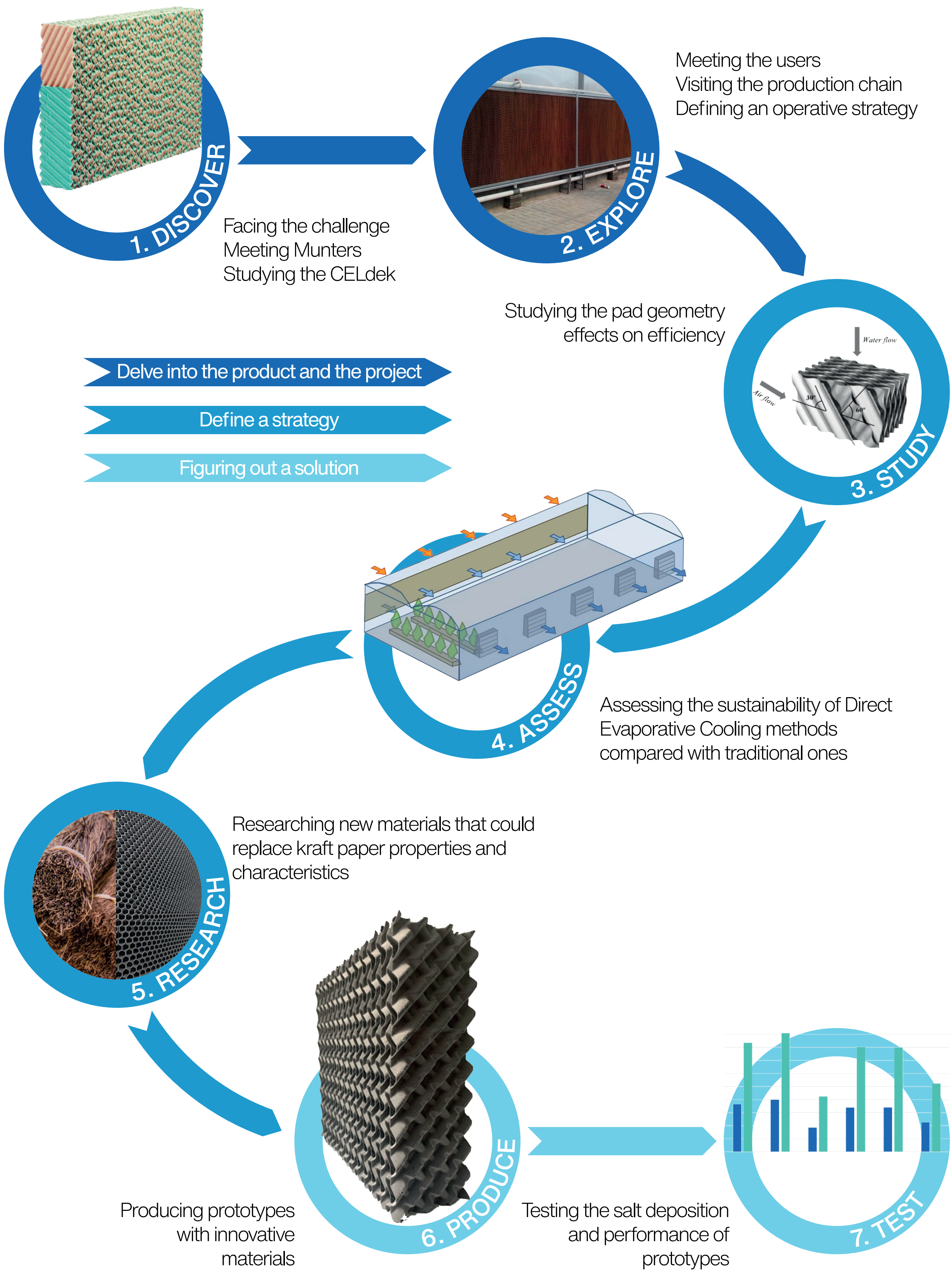
In conclusion, our project addresses critical challenges in greenhouse cooling by aiming to **reduce water consumption, improve sustainability, and enhance performance.** Stakeholder analysis guided our approach, and research into materials and experimental activities led to promising alternatives. Our goal is to provide an innovative and sustainable solution that meets the diverse needs of stakeholders, ensures water conservation, and secures the economic viability of greenhouse applications. By focusing on these strategies and technologies, we can contribute to the advancement of sustainable practices in the agricultural sector while addressing the pressing issue of water scarcity.

Key words

Direct evaporative cooling; lower water consumption; Sustainable food chain supply; Cooling performance; Testing salt deposition.

the Green Wec Roadmap

water · energy · climate



Project description written by the Principal Academic Tutor

Sustainable agriculture is becoming increasingly important, as the world population is growing rapidly. Adiabatic cooling is a very energy efficient solution for cooling greenhouses, and it is widely used in warm and hot regions, but it is also water intensive. There is thus the need to reuse polluted or unhealthy water to grow food in hot climates, and find an alternative solution to kraft paper pads with a larger durability. The GreenWEC project tried to find an innovative and economic solution to cool greenhouses through adiabatic cooling using non-paper materials and reducing water consumption while, at the same time, increasing the life time of the cooling pads. After an initial literature review on the pad materials, it was decided to concentrate on plastic materials and innovative coatings to reduce the salt deposition during the pad lifetime. The project combined applied research and numerical modelling with experimental setups to test the effectiveness of the proposed solutions. In particular, two experimental setups were designed and realized, one in Torino at the DIATI CWC laboratory in order to study the salt deposition on the pads for different materials/coatings and one in Milano at the DENERG AIR LAB laboratory in order to measure the adiabatic efficiency of the same pads before and after the salt deposition. The properties of the pads prototypes were compared and contrasted to the ones of a traditional paper-based pad.

The results show that it is possible to achieve similar performances to CELdek using different materials with lower or, in some cases, even negligible salt deposition. This would ensure good performance while allowing for the use of scarce-quality water and increasing the pad's durability, thereby enhancing the product's sustainability. The results obtained are quite promising; however, further studies are recommended, particularly regarding long-term salt deposition effects on performance and product lifecycle sustainability.

The project is aligned with the United Nations Sustainable Development Goals of Zero Hunger and Clean Water. It is also important to note that the project was focused on developing a robust and accessible technology, even for developing economies.

Team description by skill

The challenges of the project required a multidisciplinary team with a strong synergy and a common basic knowledge of the physics and thermodynamics effects of cooling and indoor environmental conditions. The academic and external tutors have radically contributed to delve into the topics related to the goals of the project, while every team member had the possibility to offer a unique perspective, based on their own field of study for the degree path. Specifically:

- **Anna Barbieri,** enrolled in Space Engineering, contributed her critical thinking skills and background in fluid dynamics to the geometric analysis. She also managed the design of the Milan setup and collaborated in the experiments conducted in the Polimi laboratories;
- **Damiano Galassi,** enrolled in Chemical and Sustainable Processes Engineering, contributed with technical and analytical skills in the research and comparison of several cooling technologies; he provided the initial design of the Turin set-up and partially collaborated in the experimentation;
- **Luca Ghisio,** enrolled in Industrial Production and Technological Innovation engineering, contributed his project management and organizational skills to the success of the GreenWEC program. He provided strategical guidance in steering the research towards economically viable solutions that could have a high integration potential with Munters' existing business model;
- **Alberto Gremo**, enrolled in the Architecture for Sustainability program, managed to enhance the project with a sustainable and environment-friendly point of view; he has contributed to the research of new materials through a literature study and to the technical design of the Milan set-up;
- **Leonardo Iacobelli,** enrolled in Mechanical Engineering, collaborated in the research and comparison of several cooling technologies; he handled both the structural and operational design of the Torino setup and involved in the actual experimental activity;
- **Angelo Matichecchia,** enrolled in Chemical Engineering, collaborated in the material selection, geometric analysis, and evaporative performance analysis, which collectively enhanced the efficiency and reliability of the evaporative cooling system.

Goal

In the contemporary global landscape, water and food resources have assumed critical importance, emerging as potential catalysts for conflicts in the forthcoming era while the pursuit of the United Nations' Sustainable Development Goals, with a focus on Zero Hunger and Clean Water as key objectives, underscores the interconnectedness of water quality and agricultural sustainability.

As the global population approaches an anticipated surge from 7.6 billion to 8.6 billion in 2030, the strain on this vital resource becomes increasingly evident. This is further exacerbated by the surge in greenhouse-based agriculture, which necessitates energy-efficient cooling solutions like adiabatic cooling, which come at the cost of heightened water consumption.

Amid this confluence of challenges and prospects, the objective of this project emerges: **to engineer an economically viable evaporative cooling technology allowing for the reduction of clean water used by such products.** This initiative seeks to address the pressing need for sustainable agriculture practices focusing on the following key goals:

1. **Innovative Cooling Technology:** Develop and prototype innovative adiabatic cooling technologies that are capable of maintaining current cooling efficiencies.

2. **Economic Viability:** Ensure that the proposed cooling solutions are economically viable, enabling cost-effective implementation for greenhouse operators and contributing to the sustainability of agricultural practices.

3. **Environmental Sustainability:** Minimize the environmental impact of greenhouse cooling by reducing water usage.

4. **Market Leadership:** Enhance Munters' position as a market leader by proactively addressing sustainability concerns, anticipating market demands, and delivering environmentally responsible solutions to clients.

By achieving these project goals, Munters aims to revolutionize greenhouse cooling technology, setting new standards for water-efficient solutions while aligning with global sustainability initiatives. This endeavor signifies Munters' dedication to innovation, market leadership, and environmental responsibility in an era where water resources are increasingly strained, and stringent regulations shape industry practices.

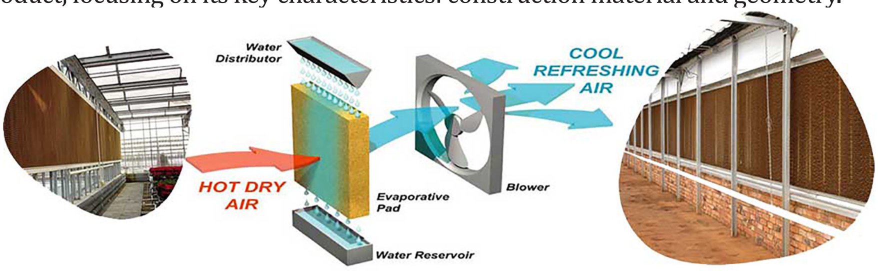
Understanding the problem

The definition and understanding of the problem were the first steps taken by the team to reach the final solution. The initial weeks were crucial for meeting with university and company tutors to grasp Munters' requirements and ideals for the project itself. The primary objective was to minimize the use of freshwater, and various branches of a solutions' framework were developed from this goal. Waters with high salt concentration might, in fact, negatively impact the lifespan of the pads, radically reducing the overall performances. Developing a framework required understanding the technical features of evaporative pads (CELdek) and the physics by which this product can ensure optimal thermal conditions inside greenhouses and broilers. Various design parameters such as material composition and geometry were discussed, and at the same time, the current performance of CELdek was compared with alternative technologies such as mechanical and absorption refrigeration cycles. Furthermore, the possibility of recovering water present in humidity via adsoprtion and stripping cycles was simulated to explore the potential for integration with Munters' existing products. Simulations conducted using commercial software (Aspen Plus) indicate that CELdek still has an edge in two fundamental aspects:

1. <u>Lower initial capital and maintenance costs</u>: this ensures the ability to serve a wide range of customers and not have to segment the market based on the proposed product.

2. <u>Lower energy consumption</u>: this translates to high energy efficiency and compliance with current energy sustainability goals. In fact, reducing water consumption at the expense of increased energy usage would be inconsistent with the project's initial objectives.

In conclusion, the only viable path to follow was the optimization of the current product, focusing on its key characteristics: construction material and geometry.

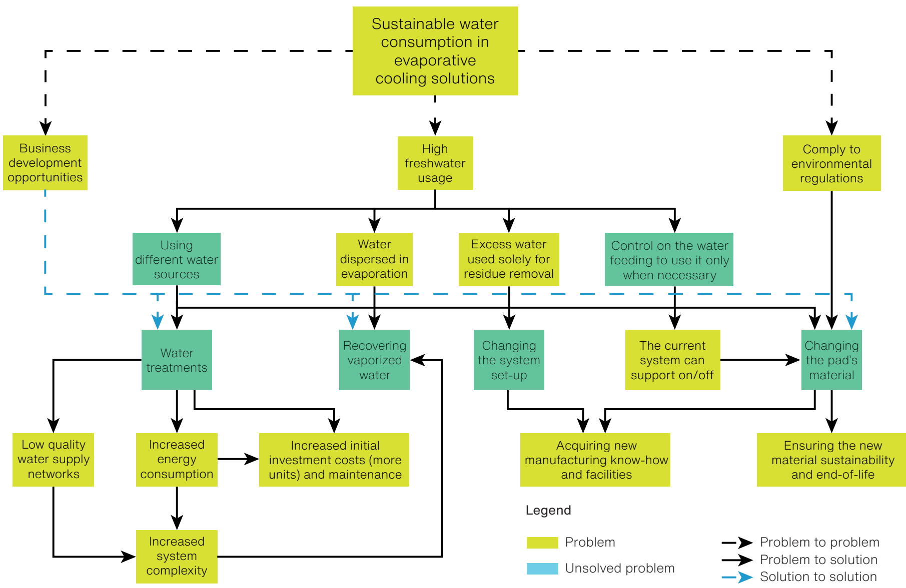


Exploring the opportunities

The work explores various opportunities and attributes related to evaporative cooling pads (DEC pads) and materials used in them:

1. **DEC Pad Attributes:** DEC pads play a crucial role in cooling systems by facilitating heat and mass transfer between air and water. Key attributes for optimal performance include:
    - Extensive water-to-air contact areas for effective air saturation.
    - Low pressure drop.
    - Easily assembled media.
    - Simplified cleaning and maintenance.
2. **Types of DEC Pads:** DEC pads are categorized into three main types based on material and design:
    - Fiber pads, often made from vegetable fibers like aspen, offering eco-friendly and affordable solutions.
    - Rigid media pads, made from materials like cellulose or PVC, with longer durability and extensive contact surfaces.
    - Package or fill pads, incorporating various porous, inorganic materials, like volcanic rocks or plastic mesh.
3. **Effect of Pad Material:** The choice of wetted media significantly affects performance, including porosity, contact area, pressure drop, and humidification time. Various materials, such as cellulose, plastic, glass fiber, coconut coir, and others, have been compared for their effectiveness.
4. **Material Selection:**
    - Among vegetable fibers, jute is highlighted as a promising option due to its cost-effectiveness, sustainability, resistance to salt deposition, and local availability. The emphasis is on utilizing local resources for tailored solutions.
    - Plastic materials, especially PVC and polyethylene, are recognized for their durability, low maintenance, resistance to salt deposition, and versatility in using alternative water sources. They offer potential in water conservation and sustainability, particularly in water-scarce regions. Their ability to be regenerated and reused is a cost-saving and eco-friendly aspect.
5. **Environmental Impact:** While PVC and polyethylene have advantages, their environmental impact and energy-intensive production must be considered. Responsible usage and recycling practices are crucial for maximizing their benefits while mitigating environmental concerns.

In conclusion, the text highlights opportunities in the selection of DEC pad materials, with a focus on vegetable fibers like jute and plastic materials like PVC and polyethylene. These materials offer potential for cost-effectiveness, sustainability, and durability in various applications, provided environmental considerations are addressed.



Generating a solution

The analysis shows that improving the performance of existing pads may not be effective in reducing water usage. Instead, the focus is on exploring alternative water sources. The main goal is to develop a cost-effective method for using non-drinkable water sources for cooling greenhouses, reducing the consumption of potable water while preserving the low energy consumption associated with this technology.

One significant issue is the accumulation of salt deposits on the pad surface, which impairs performance and longevity. The Turin experiment's objective is to test various materials and geometries to determine their resistance to salt deposition. To simulate real-world conditions, test pads are exposed to brackish water with a high salt concentration. Despite the short testing timeframe, the goal is to replicate the on/off cycles experienced by evaporative cooling pads in an accelerated manner. Five pads were tested: kraft paper pad (CelDEK, used as benchmark), PVC pad, PVC pad with rayon on the surface and two Nylon PA12 pads with different geometries.

After the salt deposition process, it was crucial to test the performance of the various materials. This was necessary because the new pad, in addition to ensuring low salt deposition, must also deliver satisfactory results in terms of deltaV reduction and efficiency to be competitive in the market and a viable alternative to CELdek. Consequently, the aged pads were transferred to the Milan laboratories, where a custom experimental setup was assembled to evaluate the performance of the different materials and geometries.

The findings indicated that CELdek suffered the most from salt deposition in comparison to other materials. Subsequently, the PVC pad with rayon inserts ranked second in susceptibility, while other plastic materials exhibited lower sensitivity to salt build-up, especially Nylon PA12 pads. Upon testing the performances of these pads in Milan, it was noted that CELdek initially performed the best but experienced a decline in performance after salt deposition. Among the other materials tested, the PVC pad with rayon inserts and the Nylon-based pad delivered the most favourable outcomes. Their performance remained on par with CELdek and did not deteriorate during the aging process. Considering both salt deposition and performance, especially in terms of temperature difference, Nylon pads emerged as a potential alternative due to their minimal salt build-up and consistent performance.

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