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CASEUS – COMBINED USE OF RENEWABLE ENERGY SOURCES TO IMPROVE ENERGY EFFICIENCY IN REFRIGERATED CHEESE RIPENING CHAMBERS

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Abstract: *This article focuses on the integrated use of various forms of renewable energy, including wind, solar thermal, and photovoltaic, combined with Phase Change Materials (PCMs), aiming to optimize energy consumption and reduce CO_2 emissions in the production of traditional ewe's cheese, with particular emphasis on the cooling system of the ripening chamber. Given the increasing global concern about climate change, with the European Union, it becomes imperative to seek sustainable solutions. The current volatility of fossil fuel prices in the international market reinforces the urgency of shifting the energy consumption paradigm, prioritizing the transition to renewable sources. This study, conducted as part of the CASEUS project, encompasses several significant phases, including analyzing the most influential variables in temperature stability and energy consumption during pasteurization, coagulation, and ripening chamber stages; evaluating energy performance; optimizing the combined use of electrical (photovoltaic and wind) and thermal (solar hot water and biomass) energy sources and implementing Phase Change Materials (PCM) to regulate the ripening chamber temperature and optimize thermal energy flows through thermal energy storage.*

Keywords: Ripening cheese chambers, renewable refrigeration, energy efficiency.

1. INTRODUCTION

Cheese production in the Alentejo region (south Portugal) has a long history that intertwines with the civilization of this area. For many centuries, the production process was entirely artisanal, with the ripening process taking place in adapted sections within the cheese maker's own home. Nowadays, the cheese production process in small-scale dairies still retains a strong artisanal character; however, the existence of ripening chambers with automatic temperature and humidity control is now widely spread [1]. Nonetheless, some aspects have remained unchanged over time, such as the energy requirements in certain critical stages of the production process.

Until the mid-20th century, the milk coagulation process and the production of whey represented the stages with the highest energy consumption, leading to the need for fuel, traditionally wood. From this point onwards, with the legal and technological changes that were introduced, these thermal processes were replaced by the use of boilers fuelled by diesel or by the direct use of propane or butane gas. Simultaneously, the cheese ripening process also underwent changes from the 1970s onwards with the introduction of ripening chambers. These chambers brought about greater homogeneity in atmospheric conditions during the ripening process, allowing the production of high-quality cheeses over a longer period throughout the year, while maintaining high standards of food safety. In today's era of heightened environmental consciousness, there arises a unique opportunity to couple tradition with innovation to enhance processes, reduce energy consumption, improve energy efficiency, and mitigate CO_2 emissions within the production of traditional Alentejo cheeses from ewe and goat milk [2]. Embracing modern technologies and sustainable practices can revolutionize every stage of the cheese-making process, from milk collection to aging [3]. Implementing renewable energy sources such as solar or wind power to fuel production facilities could drastically reduce the carbon footprint associated with energy consumption. Furthermore, optimizing heating and cooling systems and investing in energy-efficient equipment can lead to significant energy savings without compromising the quality of the final product [4, 5, 6]. In addition to reducing energy consumption and emissions, improving efficiency in Alentejo cheese production can have far-reaching positive effects on the environment. Decreased energy usage means less reliance on finite fossil fuels, thereby contributing to the preservation of natural resources. Furthermore, mitigating CO_2 emissions helps combat climate change and fosters a more sustainable future for generations to come [7, 8]. Furthermore, by embracing sustainable practices, Alentejo cheese producers can position themselves as leaders in environmental stewardship, enhancing their brand reputation and market competitiveness. Consumers are increasingly seeking out products that align with their values of sustainability and environmental responsibility, presenting a prime opportunity for producers to capitalize on this growing market demand.

2. MOTIVATION

The operation of ripening chambers used in the production of cheese in Alentejo region relies on the vapor compression cycle, encompassing four main stages: evaporation, compression, condensation, and expansion. Among these, compression is responsible for the high electricity consumption in cheese dairies, representing over 70% of the total. Indeed, the substantial electricity consumption of ripening chambers, coupled with the use of fossil gas fuels for thermal energy production in coagulation and whey production, are factors that warrant special attention given the current context of combating climate change and reducing fossil fuel dependency [9]. For the region of Alentejo, there are 57 cheese factories where the average monthly energy consumption is 7000 kWh. This results in a total monthly energy consumption for the cheese industry in the region of Alentejo of 399,000 kWh, which is equivalent to 4,389,000 kWh per year (11 months of work)【10, 11]. Also, climate change is currently a global concern, with the European Union ranking as the third-largest emitter of greenhouse gases in the world, following China and the United States. Within the EU, the top five emitters in 2019 were Germany, France, Italy, Poland, and Spain. The energy sector accounted for 77.01% of greenhouse gas emissions in the EU in 2019, followed by agriculture (10.55%), industry (9.10%), and the waste sector (3.32%). In 2021, the European Union set a target of achieving net-zero emissions by 2050 and established an interim goal of reducing emissions by 55% by 2030. Measures to achieve this goal are outlined in the "Objective 55" package, presented in 2021, which includes strengthening renewable energy production, with the reinforced target of 40% by 2030 [12]. This scenario, coupled with the current situation of high volatility in fossil fuel prices in the international market, underscores the urgency of shifting the energy consumption paradigm in cheese production. It becomes imperative to prioritize the pursuit of renewable sources while maintaining the sustainability of the sector, as well as high standards of quality and food safety.

3. PROJECT DESCRIPTION

3.1. Overview

The present project constitutes a multidisciplinary partnership involving the following areas of work: i) *Technological diagnosis*, which includes the participation of artisanal cheese dairies located in the Baixo Alentejo and Beira Baixa regions where goat cheese production occurs according to local practices. Data collection will be conducted on electricity consumption in the ripening chamber compressors and estimation of gas consumption for milk heating and whey production. Simultaneously, temperature and humidity sensors will be installed inside the ripening chambers and outside the production unit to record local climatic conditions. ii) *Optimization of system architecture* involves studying the most influential variables in temperature stability and energy consumption in the cheese maturation chamber. Optimization of the combined use of electric energy sources (photovoltaic and wind) and thermal energy sources (solar hot water and biomass) at different manufacturing stages will be studied. Additionally, the use of phase change materials (PCM) in regulating the ripening chamber temperature is planned. iii) *Construction of a cheese dairy prototype* based on the results of, a cheese dairy prototype will be implemented using thermal and electric energy obtained from renewable sources. The ripening chamber will be equipped with a continuous monitoring system of environmental conditions, including temperature and humidity. Furthermore, the system includes the installation of electric current meters (compressor, fans, and other electrical devices), biomass consumption meters (boiler), and water consumption meters (ripening chamber piping, coagulation tank, and whey tank) for energy balance calculation. The monitoring system architecture includes a set of sensors collecting prototype data transmitted via WiFi to the gateway and subsequently, via the Internet, to the server. iv) *Impact of the prototype* on the cheese's biochemical, microbiological, and sensory properties analysis of cheese will consider three maturation dates (0, 15, and 30 days) and will include rheological, colour, chemical, biochemical, sensory, and microbiological parameters. v) *Dissemination of results* involves the creation of a Facebook page with consortium identification, regularly updated with information on ongoing work, including multimedia content and testimonials from different partners. A final seminar (in-person and online) will be held at the end of the project to present the prototype and key findings. The project's main results will be published in a book for dissemination among the academic community and local partners, such as associations and cheese producers.

3.2. Objectives

This project aims to promote the use of renewable energy in a cheese factory context, aiming for the reduction of the use of fossil fuels in the pasteurization and coagulation and, simultaneously, reduce the consumption of electricity (compared to the pre-project situation) by 40%, maintaining same quality standards, as well as local cheese shops.

3.3 System optimization

With the aim of optimizing the system, and considering the utilization of renewable energies, solar thermal and photovoltaic energy, wind energy, pellet boiler, and PCMs, the following equipment has been calculated, optimized, dimensioned, and selected, as summarized in Table 1.

Table 1. CASEUS prototype equipment's.

Equipment		
Designation	Company	Model
Wind Turbine	TESUP	TESUP H7
Photovoltaic Solar Panel	TENKA Solar	TKA455M-108
Solar Collector	Vulcano	FKT-2W
Pellets Boiler	Ecoforest	Cantina Nova 30 kW
Batteries	SAJ	B1-5.1-48
Evaporator	Centauro	DF 5010 CO2
Condensing Unit/Compressor	SCM FRIGO	UMT T 030 MTDX
Humidifier	CAREL	UU01G

PCM	RUBITHERM	RT10HC
PCM	RUBITHERM	RT8HC
Pump (pasteurization tank)	GRUNDFOS	MAGNA3 25-80
Pump (accumulation tank)	GRUNDFOS	ALPHA1 25-80 N 180
Pump (boiler)	GRUNDFOS	MAGNA3 25-120
Pump (solar collector)	GRUNDFOS	MAGNA3 25-80
Pump (coagulation tank)	GRUNDFOS	MAGNA3 25-80

3.4. Developed prototype

With the aim of testing the studied solution, a real ripening chamber will be implemented in the facilities of the Polytechnic Institute of Beja, where batches of ewe's and goat's cheese will be produced. After, the consumption of energy during ripening will be analysed and compared with the energy consumption a similar installation using traditional technology (Figure 1). After ripening process, physicochemical, sensorial and microbiological analysis will be performed for characterization to the cheeses after ripening time. The general schematic principle to be implemented in the prototype is succinctly represented in Figure 2, the electrical energy produced by photovoltaic solar panels and wind turbines will be used to power the compressor of the ripening chamber. Additionally, thermal energy from the pellet boiler and solar collectors will be utilized to heat water to the temperatures required for the pasteurization and coagulation processes, respectively. Phase Change Materials (PCMs) will also be incorporated inside the ripening chamber to decrease the energy demand of the refrigeration system. CO_2 emissions in this optimized process will be analysed and compared with those of the traditional process. This comparison will allow assessing the environmental impact of implementing the new system and identifying opportunities to reduce greenhouse gas emissions.

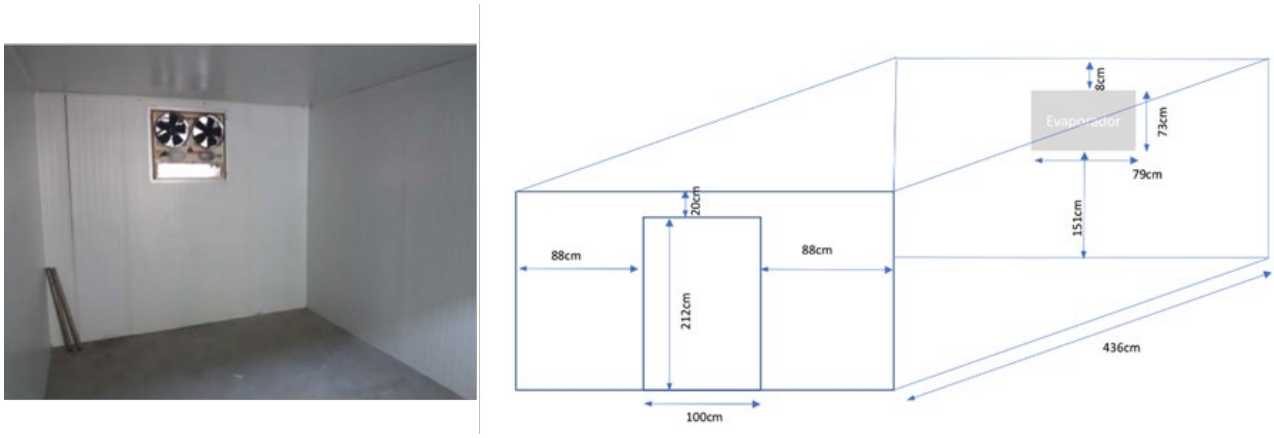

Figure 1. Implemented cheese ripening chamber.

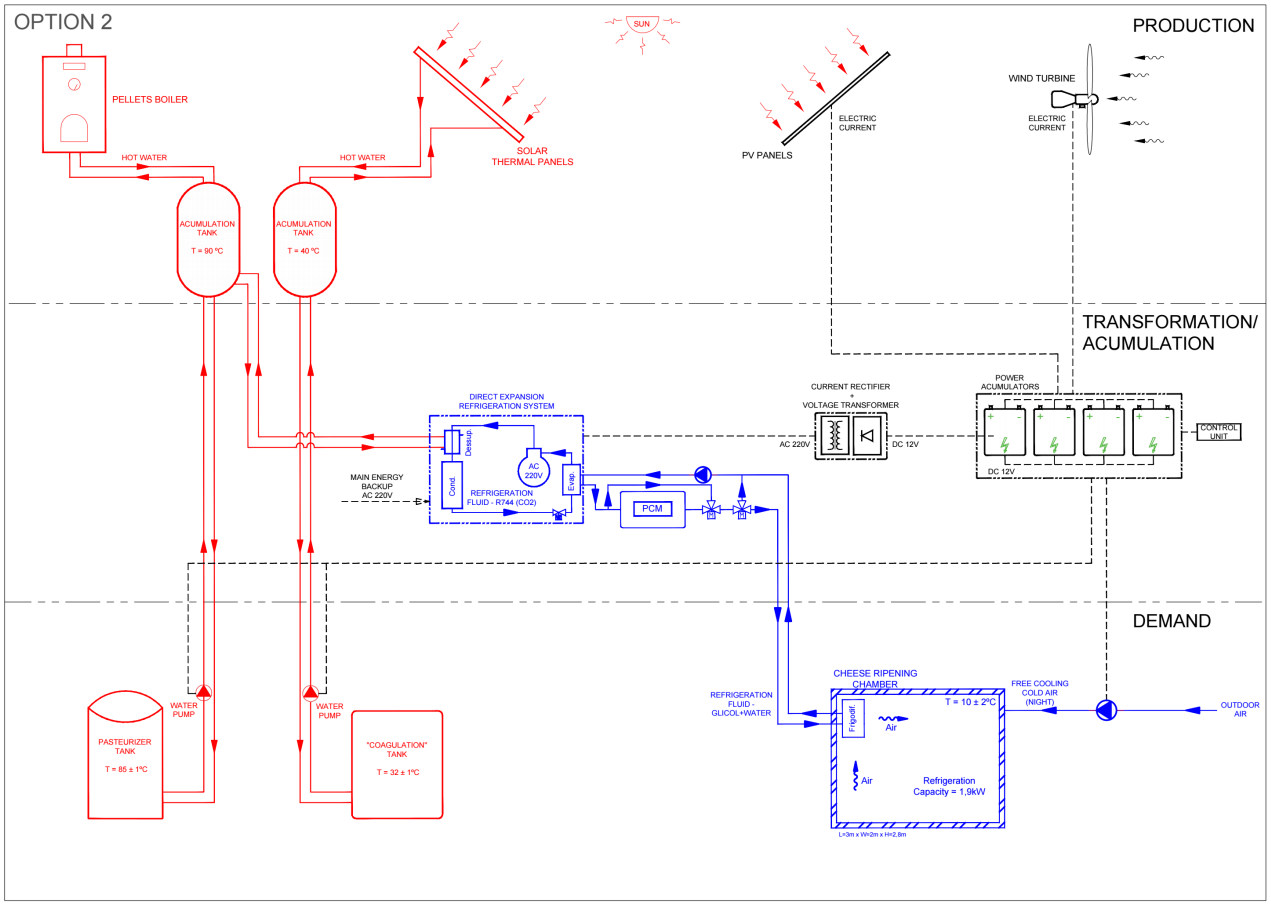

Figure 2. General CASEUS working principle.

4. CONCLUSIONS

CASEUS project represents a significant endeavor aimed at addressing the pressing need for sustainable energy solutions in the cheese production industry. By integrating various forms of renewable energy and innovative technologies, such as wind, solar thermal, photovoltaic, and Phase Change Materials (PCMs), the project seeks to optimize energy consumption and reduce CO_2 emissions, particularly in the cooling system of cheese ripening chambers.

The project's objectives were meticulously pursued through several phases, including energy diagnosis, process engineering, laboratory analysis, and results dissemination. Notably, the implementation of a cheese dairy prototype at the Polytechnic Institute of Beja allowed for the production of traditional Alentejo goat cheese under controlled conditions, enabling the thorough monitoring of energy consumption and the assessment of environmental impacts.

The utilization of renewable energy sources, coupled with the integration of PCMs for temperature regulation, shows promising results in terms of energy efficiency and environmental sustainability. The comparison between the optimized process and traditional methods revealed significant potential for reducing greenhouse gas emissions and mitigating the industry's carbon footprint.

Moving forward, the insights gained from this project will inform future endeavors in the pursuit of sustainable practices within the cheese production sector. Continued research and innovation in renewable energy technologies will be essential for achieving long-term environmental objectives and ensuring the resilience of the industry in the face of climate change challenges.

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