# Clustering through stakeholders' engagement
# Deliverable 6.4
# WP6.4 Case studies report

**Project title**

RES4LIVE - Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption

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# DELIVERABLE FACTSHEET

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# ABBREVIATIONS

| | | |
|---|---|---|
| **WOS** | : | Web of Science |
| **BFS** | : | Breadth-First Search |
| **EU** | : | European Union |
| **LUT** | : | Look-Up-Table |
| **MAPE** | : | Mean Absolute Percentage Error |
| **MPE** | : | Mean Percentage Error |
| **PV** | : | Photovoltaics |
| **PVGIS** | : | Photovoltaic Geographical Information System |
| **PVT** | : | Photovoltaic Thermal (Photovoltaic Thermal Hybrid Solar Collector) |
| **RES** | : | Renewable Energy Sources |
| **WP** | : | Work Package |
| **AOZ** | : | Animal Occupied Zone |

# PARTNERS' SHORT NAMES

**AUA** - AGRICULTURAL UNIVERSITY OF ATHENS

**UNIBO** - UNIVERSITY OF BOLOGNA

**ATB** - LEIBNIZ INSTITUTE FOR AGRICULTURAL ENGINEERING AND BIOECONOMY

**EV ILVO** - RESEARCH INSTITUTE FOR AGRICULTURE, FISHERIES AND FOOD

**UGENT** - GHENT UNIVERSITY

**CERTH** - CENTRE FOR RESEARCH AND TECHNOLOGY-HELLAS

**AU** - AARHUS UNIVERSITY

**LVAT** - LEHR- UND VERSUCHSANSTALT FÜR TIERZUCHT UND TIERHALTUNG GROß KREUTZ E.V.

**PSYCTOTHERM** - G. LIGEROS & SIA OE

**PLEGMA LABS** - PLEGMA LABS TECHNOLOGIKES LYSEIS ANONYMOS ETAIRIA

**CRMT SAS -** CENTRE DE RECHERCHES EN MACHINES THERMIQUES

**TERRA** - TERRA ENERGY

**MG SUSTAINABLE** - MG SUSTAINABLE ENGINEERING AB

**CETRI** - CENTER FOR TECHNOLOGY RESEARCH & INNOVATION LTD

**GOLINELLI** - GOLINELLI GIULIO

**EAAP** - FEDERAZIONE EUROPEA PER LA ZOOTECNICA

**EUREC** - EUREC EESV

# PUBLISHABLE SUMMARY

As part of this deliverable, new "case studies" were developed using real energy data collected from at least 15 existing farms across various locations in Greece, Italy, and Belgium. These farms represented different scales and types of livestock farming, as well as diverse climate zones. The collected data was used to map the heat load of each farm based on a custom model developed under Task 3.4.

However, the data collection process extended beyond the planned timeline due to a lack of responses from a significant number of livestock farmers surveyed. Although additional farmers were approached and some data was gathered, the information obtained was insufficient in both quantity and quality to yield meaningful results from the model. Consequently, the fifteen case studies highlighted unique energy upgrade challenges for each farm, making it impossible to draw common conclusions regarding their energy improvement strategies.

Given these limitations, the farm-specific model was further analyzed under extreme conditions by varying individual system parameters (parametric analysis). This analysis focused on the two main farm types—poultry and pig farms—to examine the differences that arise under new conditions.

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# 1 INTRODUCTION

The objective of Task 6.1 is to analyze real livestock farm data using the farm-specific tools developed in Task 3.4 and validated in Task 5.1. To achieve this, the task targeted various cases considering factors such as the type and size of livestock, the age and scale of the installations, and the differing heating requirements across geographical areas. These factors were essential for evaluating the necessary thermal comfort for the animals and the indoor conditions required in each case study. The initial goal was to collect a comprehensive dataset from more than 15 different case studies. Sections 2 to 5 of the deliverable outline the work conducted within this framework.

However, the data collected were deemed insufficient to produce meaningful outcomes using the developed model. As a result, a series of parametric studies were conducted, focusing on two pilot farms (ILVO and AUA). These studies are presented in Section 6, which concludes the deliverable.

## 1.1 Methodology

The initial methodology was developed in collecting, through all RES4LIVE partners, an initial set of data regarding farms. Targeting to contact locally as many farms as possible in order to seek some basic information regarding those farms (ANNEX A). From the amount of data that would be collected in the first step, in the second step we will focus on those that cover the following two parameters: 1$^{st}$ fulfil the best of the above-targeted elements (size, location, type, etc.) and 2$^{nd}$ compiled with the cases studied less according to the recent literature.

Regarding the second parameter, we conducted two bibliometric analyses, on the Web of Science platform (WOS), to retrieve some qualitative and quantitative data on the matter of our interest (Moral-Munoz, et al., 2019).

A bibliometric analysis was conducted in the WOS database with VOSviewer software, which is used for constructing and visualizing bibliometric networks. More specifically VOSviewer networks “may include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations. VOSviewer also offers text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature”[1]. Eck et al. (2014) emphasized therefore “it is one of the best options for performing a science mapping analysis”.

Herein can be used to analyze relations and interrelations between concepts in the livestock field. More specifically, Figure 1 shows the results of a bibliometric analysis of all findings corresponding to 180 papers in relation to “livestock” and “animal comfort”. In Figure 2 the outcome of the bibliometric analysis of all the findings on WOS, corresponding to 598 papers concerning “livestock” and “smart” is presented. In both cases, the number of clusters is determined by the same resolution parameter, corresponding to a minimum number of 4, i.e. the repetition of the common term at least 4 times or more, assurances of the common keywords on the same group of paper analysed (180 and 598 respectively). The clusters are represented by a different colour and correspond to a stronger connection within the cluster in relation to the connection between the clusters.

[1] https://researchguides.uic.edu/bibliometrics/vosviewer accessed at 11.05.2024

In the case of the analysis of 180 papers related to "livestock" and "animal comfort", the stronger correlations, as shown in Figure 1, are mostly the following: feeding behaviour - livestock production - animal welfare - animal health, ventilation – DFD analysis – prediction - convective heat-transfer – humidity – air quality and emissions, microclimate-growth-adaptation- milk production - heat stress-strategies. Those results indicate the need to analyze and control the animal's growth environment. In all cases presented results that have to do with mostly cows and following sheep and pigs, regarding the animal capital. Those results do not conclude categories of animals such as poultry, indicating a dearth of literature on it. It is worth noticing that there were very few results – only 180 on WOS- regarding livestock and animal comfort, even though these parameters play a decisive role in the qualitative and economic maintenance and development of a livestock farm.

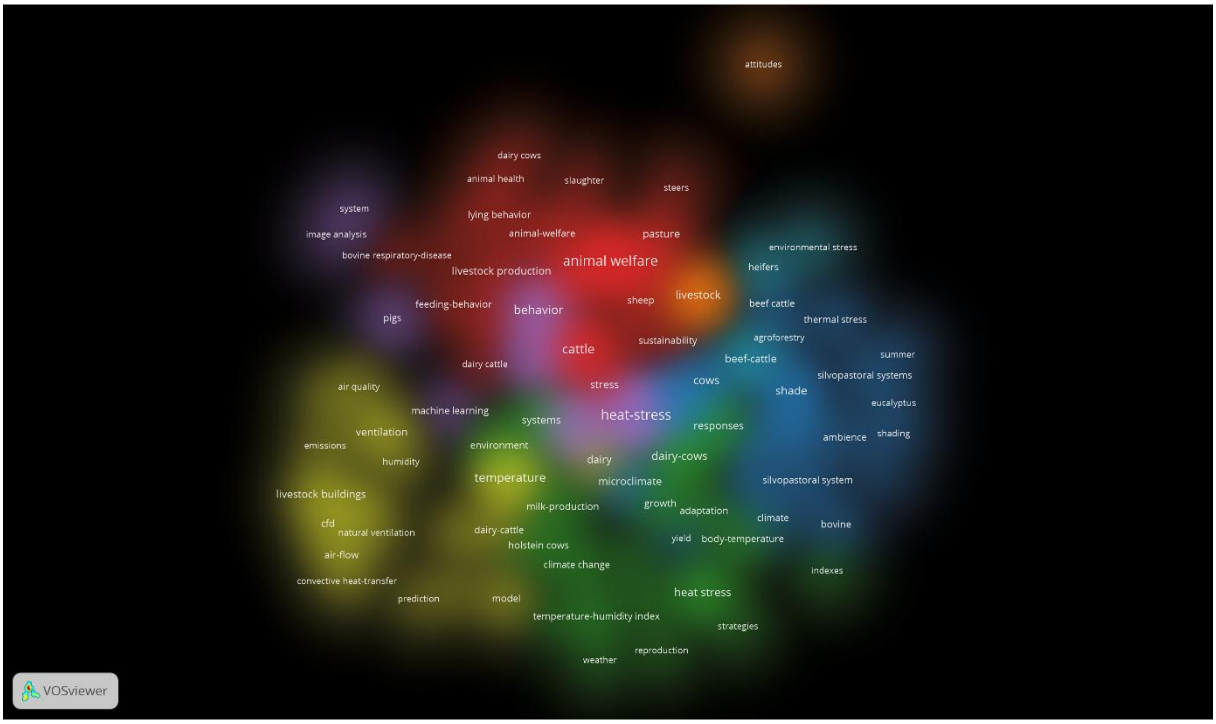



*Figure 1: Bibliometric analysis of 180 papers concerning "livestock" and "animal comfort" retrieved from WOS.*

In the case of the analysis of 598 papers (Figure 2) concerning "livestock" and "smart" the stronger correlations, as presented in Figure 1, are mostly the following: mitigation - emissions - climate change - climate-smart agriculture, adoption/adaptation - smart farming - technologies - climate-smart agriculture, technology- IoT- management - precision livestock farming - internet - smart agriculture - behaviour/cattle. Those results, both in terms of volume and final outputs, indicate the turn in adopting advanced technologies and data-driven farm processes to improve the operations of livestock farming systems targeting mitigation of direct and indirect emissions. Again, it is worth noting that there were very few results – 598 on WOS - regarding "livestock" and "smart". The first publication was made only recently, in 2002, by Herzberg H. and her colleagues, indicating the fertile field for further research.

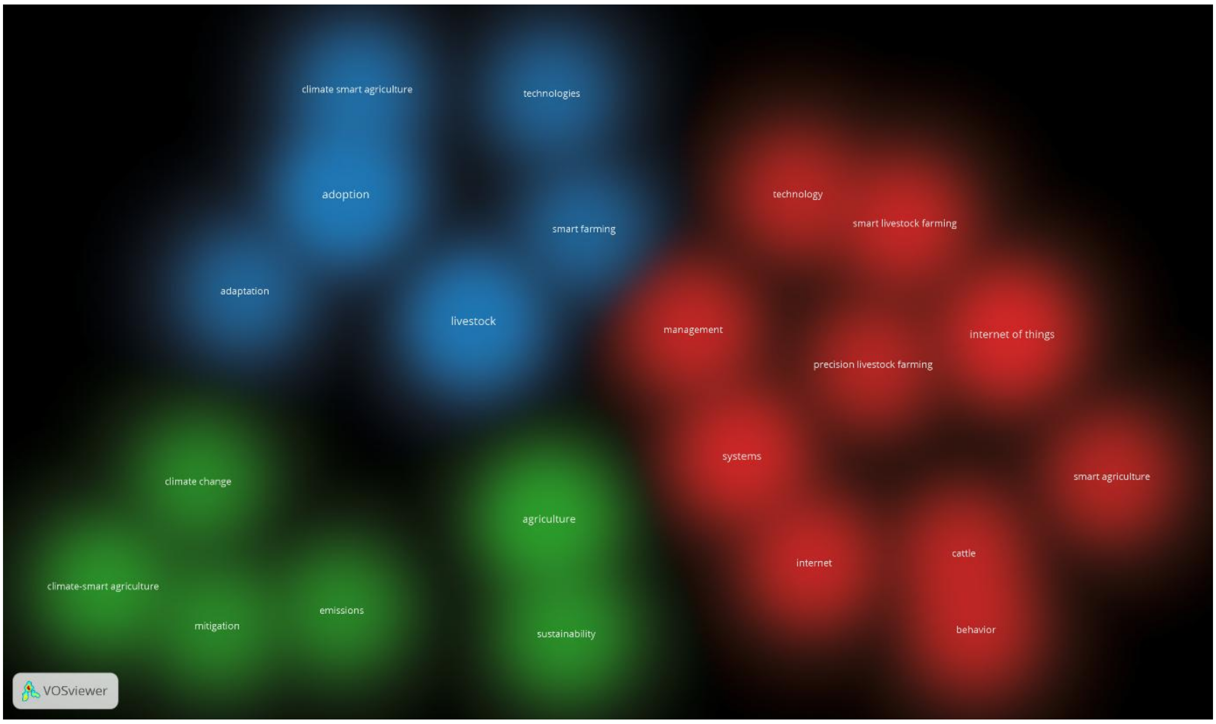



*Figure 2: Bibliometric analysis of 598 papers concerning "livestock" and "smart" retrieved from WOS.*

The overall results reveal that livestock farming is in direct correlation with technological upgrades towards both climate change mitigation and animal welfare. For those reasons, the targeted groups of livestock farms that are considered more attractive for study and analysis in this task, are those host different animal capital and different final products. Additionally, the desired new cases are located in different climate zones and have different volumes and densities.

## 1.2 Main limitations

The above methodology was followed for the data collection. The timeframe to collect the initial data from the different countries was 3 months so in the following 4 months to retrieve a more complete picture of the cases of our interest. Unfortunately, it was not possible at this time to collect the initial data in time.

At the local level, the farms that were contacted did not show particular interest in providing specific data regarding their energy consumption, nor detailed information about their installations. This is mainly due to the fact that they also did not have sufficient data, especially regarding the smaller installations.

Data were collected for the minimum number of 15 farms. Data were collected with the help of partners involved with the initial pilot farms, but still, the data collected was not complete in all cases.

Finally, the case specific models for pig & poultry farms which were produced in T3.4 were tested for variations occurring under different model development parameters from the farms they were applied to.

Most of the new set of participants wish to remain anonymous.

# 2 OVERVIEW OF THE ELABORATED NEW CASE STUDIES

One of the objectives of this section was to collect data related not only to different livestock farm types but also to different sizes and oldness. This was in order to study the thermal needs of a variety of different conditions.

*Table 1: The 15 new livestock farm cases.*

| Northern European Climate Zone | | | | Western European Climate Zone | |
|---|---|---|---|---|---|
| **Case identifier** | **Type of farm** | **Case identifier** | **Type of farm** | **Case identifier** | **Type of farm** |
| **A1** | Poultry Broiler | **B1** | Dairy Cattle | **C1** | Farrow to finish sow farm |
| **A2** | Laying hens | **B2** | Fattening Pigs | **C2** | Dairy farm |
| **A3** | Poultry Broiler | **B3** | Fattening Pigs | **C3** | Broiler |
| **A4** | Laying hens | **B4** | Dairy Cattle | **C4** | Laying hens |
| **A5** | Laying hens | | | **C5** | Broiler |
| **A6** | Broiler turkey | | | | |

Data was collected from three European countries, Greece ("A" cases), Italy ("B" cases), and Belgium ("C" cases). The 15 farm cases correspond to two different climate zones. The aggregate data are presented below in Table 1.

To manage the new case studies, the methodology followed in WP3.4 was used with estimates where needed and possible.

An overview of the European climate zones is presented in Figure 3 below:

| | | |
|---|---|---|
| BLUE | Northern European areas | Nordic climate<br>***(cold winters and mild humid summers)*** |
| PURPLE | Middle and Eastern European areas | Eastern-continental climate<br>***(cold winters and hot, dry summers)*** |
| GREEN | Western European areas | Oceanic climate<br>***(mild winters and humid summers)*** |
| ORANGE | Southern European areas and the Middle East | Mediterranean climate |

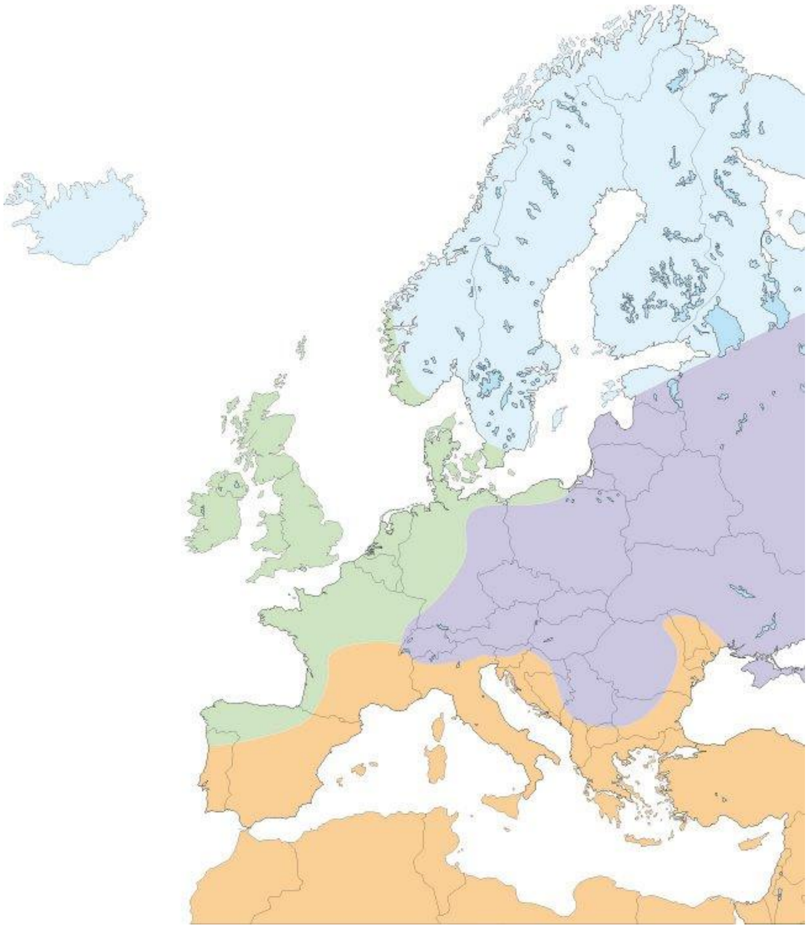


*Figure 3: Different climate zones in Europe based on geoclimatic data.*
https://www.barenbrug.biz/climate-zones-europe-and-mediterranean (accessed at 18.08.24 assessed at 23.07.2024)

## 2.1 Overview of livestock farms based in Greece (Poultry)

Poultry farming in Greece is a highly developed sector and one of the best organized in Greek livestock farming. It is indicative that according to the Directorate of Agricultural Statistics & Documentation of the Ministry of Rural Development & Food, the Greek production of eggs for human consumption in 2019 covered the domestic demand by 84.8% (Arsenios, 2021).

According to the data of the Greek Ministry of Agricultural Development and Food report of 7/1/2022, in 2021, 803 poultry and egg-producing enterprises were operating in the Greek territory. Of those, 42 are organic, 275 are free-range, 222 are barn-raised and finally 264 are in enriched cages.

Poultry farming in Greece is one of the most dynamic branches of the agricultural economy and currently represents 5% of the total value of agricultural production. Organized poultry farms in Greece produce 120,000,000 chickens and 1,500,000,000 eggs annually. Production almost completely covers the domestic demand. About 50 companies of various sizes are active in the sector. About 2,000 farmers and poultry farmers are active in animal production and cooperate with organized vertical enterprises. Chicken production is concentrated by 45% in Epirus, by 27% in Central Greece and by

18% in Macedonia and Thrace. Egg production is more evenly distributed, but a large percentage still comes from the Attica region (Figure 4). Systematic egg production is carried out by approximately 649 enterprises distributed throughout the country. It is worth noting that only 13 of them produce approximately 41% of the total eggs produced in Greece (Goliomytis, 2015) [2].

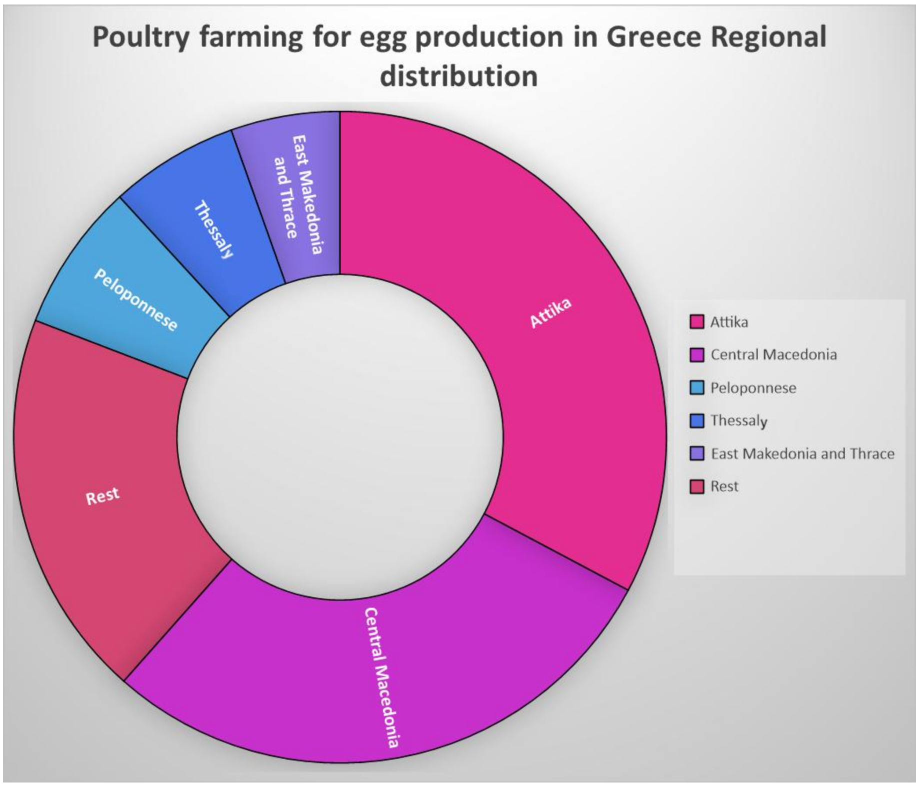



*Figure 4 Poultry farming for egg production in Greece.*
*Data retrieved from:*[https://www.minagric.gr/images/stories/docs/agrotis/poulerika/ektrofh_poulerikon_avgon280624.pdf](https://www.minagric.gr/images/stories/docs/agrotis/poulerika/ektrofh_poulerikon_avgon280624.pdf) *(in Greek)*

## 2.2 Overview of livestock farms based in Italy (Cattle & Pigs)

Italy's livestock sector is described as an "intensive livestock farming" one. Italian livestock production is projected to reach 8.5 million heads by 2026, down 1% from 2021. The total cattle population was estimated in December 2023 at 5.582.1030 (number of heads) and 9.171.160 pigs (number of heads) at the same period[3].

The average density of the Italian cattle population is shown in Figure 5, where a large concentration is captured in northern Italy. No additional data for the pig population were found.

[2] https://mediasrv.aua.gr/eclass/modules/document/file.php/EZPY100/%CE%95%CF%81%CE%B3%CE%B1%CF%83%CF%84%CE%AE%CF%81%CE%B9%CE%BF/%CE%96%CE%A9%CE%9F%CE%A4%CE%95%CE%A7%CE%9D%CE%99%CE%91%20%20%CE%A0%CE%A4%CE%97%CE%9D%CE%9F%CE%A4%CE%A1%CE%9F%CE%A6%CE%95%CE%99%CE%9F.pdf (in Greek)

[3] http://dati.istat.it/Index.aspx?QueryId=24664&lang=en accessed at 01.09.2024

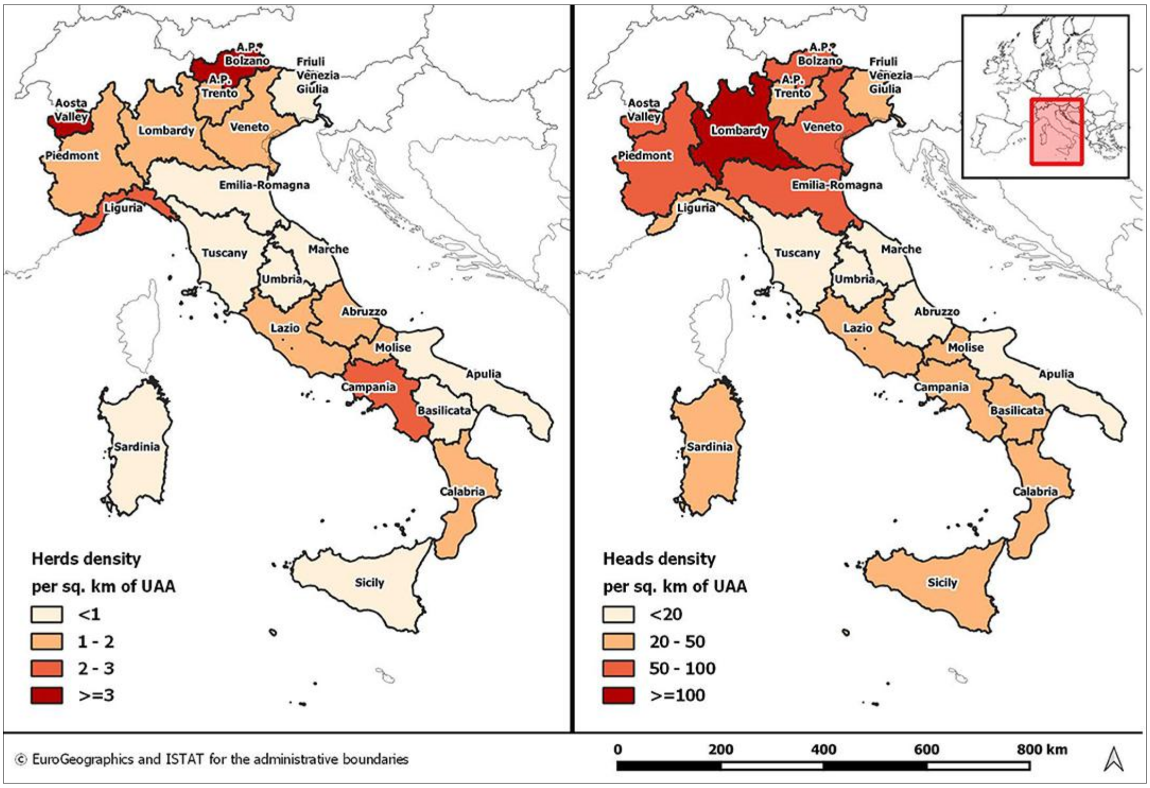



*Figure 5: Average density of Italian cattle population per km2 of Utilized Agricultural Area (UAA) as of 30th June 2020. (source: Margin et al., 2022)*

## 2.3 Overview of livestock farms based in Belgium (Cattle, Pigs & Poultry)

Pig and cattle inventories continue to have a declining population rota in Belgium. At the same time, a reverse course occurred in poultry, goat and sheep.

The pig inventory decreased in October 2023, compared to the previous year as well as the number of farms. More specifically in the more intensive farming area of Flanders, the number of farms decreased by 7.4%, while in Wallonia by 11.6%.

The cattle inventory also decreased in 2023. More specifically, there were 2.25 million animals in 2023, and 2.21 million in 2022. As before, the number of cattle farms in Belgium also decreased by 3.3%.

On the other hand, the poultry sector followed the opposite course. It increased by 2.3% in 2023, which is attributable to the increase in the broiler chicken subsector. This increase was offset by a 9.9% decrease in poultry farms.

The overall animal production value in Belgium, in 2022, is depicted in the diagram in Figure 7, where dairy and pig products dominate.

On the graph below there is an outlook of the animal production value in Belgium in 2022 where milk products and pigs dominate.

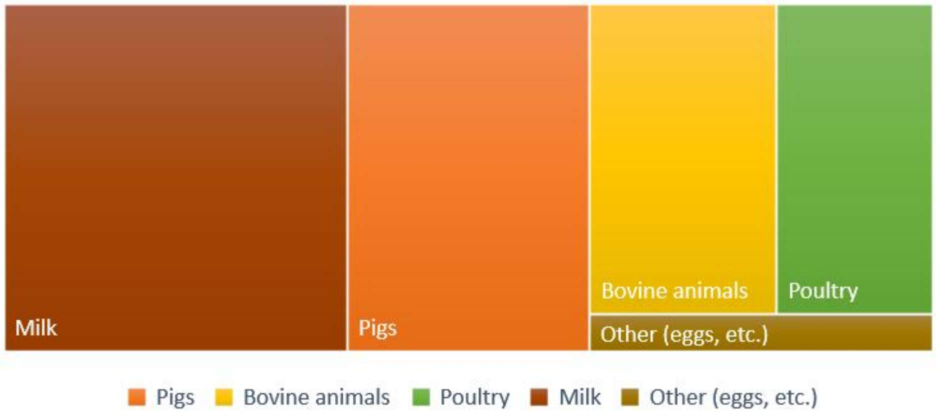



*Figure 6: Breakdown of animal production value in 2022.*
*Data retrieved from: https://statbel.fgov.be/en/news/key-figures-agriculture-2023 (accessed at 09.09.2024)*

## 2.4 Outcome pre-overview

Knowing a building's peak heat flow is essential for the effective installation of a low-carbon heating system. As a result, during the coldest months of the heating season, the new heating technology can be appropriately proportioned to satisfy the need for warmth[4].

Generally, the heat pump's size will be indicated by the maximum heat loss through the building without considering the load from living organisms; however, other elements will also affect the heat pump's size (Bandyopadhyay & Banerjee, 2022).

The building’s thermal capacity is calculated in most cases to conclude the peak building heat loss. Estimations and assumptions were needed, due to the lack and adaptability of the provided data.

[4] https://www.ifeu.de/fileadmin/uploads/Publikationen/Energie/ifeu_rap_2023_Towards_low_flow_temperatures.pdf

# 3 THE GREEK CASES

In the current section, the aggregated data concerning the farms located in Greece are presented. All six farms are located in climate zone B[5], at an altitude of less than 500 m, and refer to different cases of poultry farms. In many of them, estimates had to be made for structural elements in terms of application material. In a few of them, the number and size of openings had to be estimated as well. Table 2 below summarizes the basic elements of the case studies collected in Greece:

*Table 2: Basic elements of the case studies collected in Greece.*

| Case identifier | Type of farm | No. of housed animals | Location | Final product per year | Total Surface area (m$^2$) |
|---|---|---|---|---|---|
| **A1** | Poultry farm for meat production | 20.000 | Arta | 116100 kg | 1300 |
| **A2** | Laying hens | 800 | Arta | 258400 eggs | 82 |
| **A3** | Poultry Broiler | 12.000 | Arta | 69720 kg | 730 |
| **A4** | Laying hens | 2000 | Megara | 580000 eggs | 240 |
| **A5** | Laying hens | 500 | Megara | 167.500 eggs | 50 |
| **A6** | Turkeys farm for meat production | 120 | Agios Dimitrios, Attiki | 1690 kg | 37.5 |

## 3.1 The “A1” Greek Case

This first case with the reference name A1 corresponds to a poultry farm for meat production of 20.000 hens per season, 120.000 hens per year. The total surface area of the installation is 1300 m$^2$ (32 m x 40,6 m x 3.5 m). The main building axis has an east-west orientation with its longest dimensions having a north-south orientation. No specific data was given on the layout of the facility. The facility is located near Arta, in the region of Epirus.

This case, A1, was the only case where the producer provided adequate details about possible renewable energy installations on the premises. More specifically, they estimated that biomass, wind, sun and geothermal energy are possible sustainable practices for the current installation.

[5] http://www.opengov.gr/minenv/?p=189 (in Greek)

Regarding biomass, the suggestion was electricity generation from chicken manure. A potentially valid perspective, as mentioned in the recent bibliography (Tanczuk et al, 2019; Florin et. Al., 2019). Sun and wind power could be utilized for generating electricity for lighting, and geothermal energy could be used for heating the space as well as the water used to clean the facilities. No further details were given.

For the roof and walls, polyurethane panels of 5mm thickness are used. The floor of the poultry house is assumed to be laid on a concrete slab directly in contact with the ground. The 6 doors are made of polyurethane panels. No further details were given.

In Table 3, the main thermophysical and geometrical properties of the envelope of the A1 poultry house are presented, as calculated with the available data.

*Table 3 Main thermophysical and geometrical properties of the envelope of the A1 poultry house.*

| **Building components** | | **Area [m$^2$]** | **U-value [W m$^{-2}$ K$^{-1}$]** |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 1300 | 0,43 |
| | Rooflights | - | |
| Vertical structural elements | Wall | 508,20 | 0,43 |
| | Window | - | |
| | Door (6 in total) | Same material as the walls | |
| Horizontal (floor) | Floor | 1300 | 0,92 |

In the installation, 14 ventilators 50 inches each, evaporative cooling pads (no additional data provided), an air heater (no additional data provided) and LED lamps (no additional data provided) are used.

The building's thermal capacity was calculated at 1.948 W/K, under 4.4air changes per hour and winter outdoor design temperature of -2 °C the peak building heat loss was estimated at 189.66 kW. Those are the needs that have to be met to reach the mean set point temperature of 20 °C inside the farm.

In A1 farm electrical energy and diesel are used. The data received are incomplete and no estimations can be made regarding specific propositions for low or no-emissions energy solutions. Following are the data of the actual energy consumptions, for one year period (reference year 2023) collected from the farm:

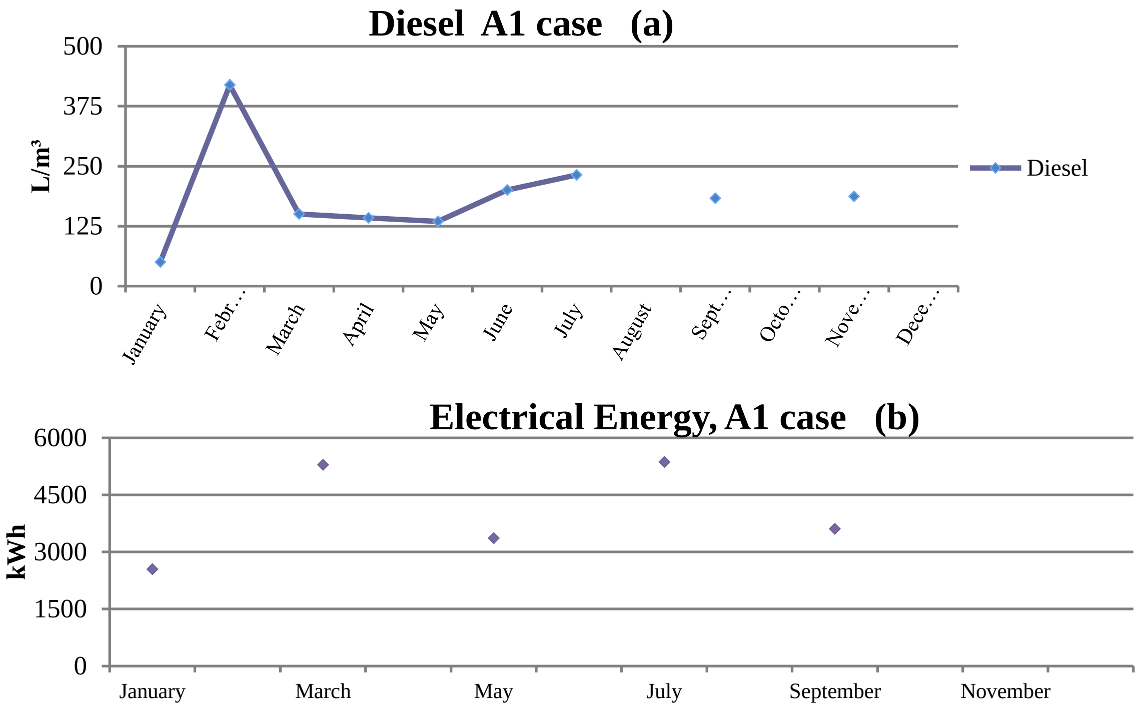



*Figure 7: Diesel (a) and electrical energy(b) consumption during 2023 for farm A1.*

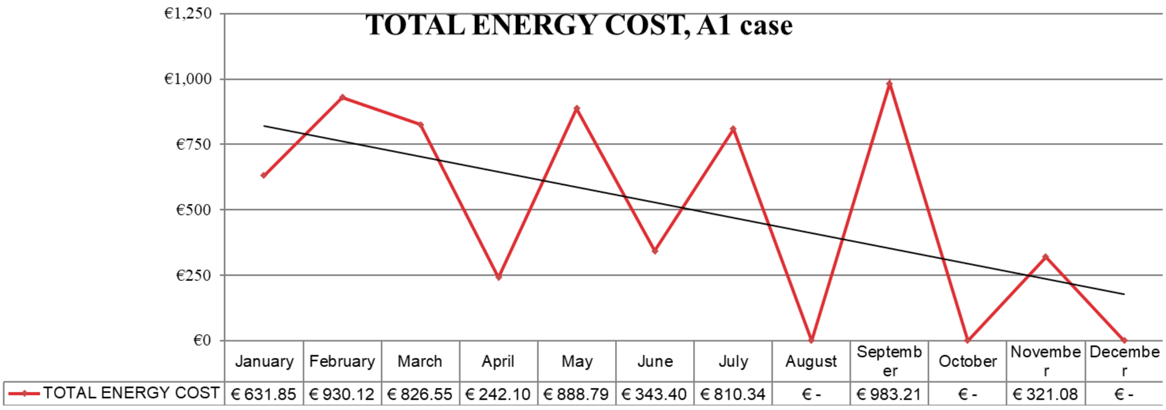



*Figure 8: Total energy cost for the case A1.*

## 3.2 The "A2" Greek Case

This second case with the reference name A2 corresponds to a relatively old poultry farm for egg production with 800 hens. The total surface area of the installation is 240 m$^2$ (25 m x 9.6 m - height of 3.9 m at the highest point). No other data was given on the layout of the facility; therefore, estimations were made for a wall made of single solid bricks. The facility is located at Megara, in the region of Attica.

For the roof polyurethane panels of 5mm were used. The walls were made of a single layer of bricks. The floor of the poultry house is assumed to be laid on a concrete slab directly in contact with the ground.

There are 2 doors (~ 104 mm x 225 mm) made of polyurethane panel (5 mm thickness)

In Table 4 the main thermophysical and geometrical properties of the envelope of the A2 poultry house as calculated under the available data are presented.

*Table 4: The main thermophysical and geometrical properties of the envelope of the A2 poultry house.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 82 | 0.43 |
| Vertical structural elements | Wall | 102.48 | 1.56 |
| | Window | 4.87 | 4.96 |
| | Door | 4.68 | 0.26 |
| Horizontal (floor) | Floor | 82 | 0.9 |

No additional data was provided on ventilation and heating systems at the time the data was collected.

The building's thermal capacity was calculated at 294 W/K, under 2.8 air changes per hour and a winter outdoor design temperature of -2°C. The peak building heat losses were calculated at 11.18 kW. Those are the needs that have to be met in order to reach the mean set point temperature of no less than 20 °C.

No energy logs were delivered. In any case, a small PV system could potentially meet the needs of the A2 installation.

## 3.3 The "A3" Greek Case

This third case with the code name A3 corresponds to a poultry farm for meat production of 12.000 volume of hens per season. The total surface area of the installation is 730m2 (29.2mX25m X2.8m), We estimate that the main building axis has an east–west orientation with its longest dimensions having a north–south orientation. No specific data was given on the layout of the facility.

There are 6 windows single glass windows (140X58mm), of which 5 are covered with used polyurethane panels (3mm thickness) and 2 metal doors (~104X225mm) both with polyurethane core (thickness 4.5cm).

The facility is located near Arta, in the region of Epirus.

In Table 5 the main thermophysical and geometrical properties of the envelope of the A1 poultry house, as calculated under the available data, are presented.

*Table 5: The main thermophysical and geometrical properties of the envelope of the A3 poultry house.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 730 | 0.43 |
| Vertical structural elements | Wall | 147.5 | 1.26 |
| | Window | 11.37 | 1.22 |
| | Door | 4.68 | 0.36 |
| Horizontal (floor) | Floor | 730 | 0.9 |

No additional data was provided on ventilation and heating systems at the time the data was collected.

The building thermal capacity was calculated at 1172W/K, and under 5.8 air changes per hour and winter outdoor design temperature of -2°C, the peak building heat losses were estimated at 112.73kW. Those are the needs that have to be met to reach the mean set point temperature of no less than 20 °C.

## 3.4 The "A4" Greek Case

The case with the reference name A4 corresponds to a relatively new poultry farm for egg production with 800 hens. The total surface area of the installation is 82m$^2$ (10.5 m 7.8 m - height of 2.8 m). The seasonal size of the unit in terms of animal capital is 2000 hens. The covering of the building has been made of a heat-insulating roof panel, consisting of two galvanized and coloured steel sheets 0.5 mm external, and 0.45 mm internal which include eco-friendly and self-extinguishing polyurethane foam. The nominal thickness of the panels is 80 mm. The building has two metal sliding doors (~ 104 x 225 mm) as well as 1 metal opening door. No other data was given on the layout of the facility; therefore, estimations were made. The facility is located near Arta, in the region of Epirus.

In the table below are presented the main thermophysical and geometrical properties of the envelope of the A4 poultry house.

*Table 6: The main thermophysical and geometrical properties of the envelope of the A4 poultry house.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 168 | 0.15 |
| Vertical structural elements | Wall | 166,8 | 0.18 |
| | Window | - | - |
| | Door | 7,02 | 0.36 |
| Horizontal (floor) | Floor | 240 | 0.91 |

No additional data was provided on ventilation and heating systems at the time the data was collected.

The building's thermal capacity was calculated at 276 W/K, under 3.65 air changes per hour and a winter outdoor design temperature of 0 °C. The peak building heat losses were calculated at 24.21kW.

Those are the needs that have to be met in order to reach the mean set point temperature of no less than 20 °C. Finally, no energy logs were delivered.

## 3.5 The "A5" Greek Case

The A5 case corresponds to a relatively new poultry farm for egg production with 800 hens. The total surface area of the installation is 50m$^2$ (16.7 m x 3 m - height of 2.2 m). ). The seasonal size of the unit in terms of animal capital is 500 hens. The covering of the building has been made of a heat-insulating roof panel, consisting of two galvanized and coloured steel sheets 0.5 mm external, and 0.45 mm internal which include eco-friendly and self-extinguishing polyurethane foam. The nominal thickness of the panels is 80mm. The building has two metal sliding doors (~98X190mm). No other data was given on the layout of the facility; therefore, an estimation was made. The facility is located near Arta, in the region of Epirus.

In the table below are presented the main thermophysical and geometrical properties of the envelope of the A4 poultry house.

*Table 7: The main thermophysical and geometrical properties of the envelope of the A5 poultry house.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 50 | 0.15 |
| Vertical structural elements | Wall | 82.8 | 0.18 |
| | Window | - | - |
| | Door | 3.61 | 0.38 |
| Horizontal (floor) | Floor | 50 | 0.91 |

The building thermal capacity is calculated at 69 W/K, under 4.5 air changes per hour and for a winter outdoor design temperature of 0°C the peak building heat losses were calculated at 4.69 kW. Those are the needs that have to be met in order to reach the mean set point temperature of 20 °C on the farm. Once again, no energy logs were provided.

## 3.6 The "A6" Greek Case

Case A6 corresponds to a pilot turkey farm for the meat production of 120 animals. The total surface area of the installation is 23 m$^2$ (5.70 m x 6.5 m x 3 m). The facility is located near Agios Dimitrios, in the region of Attica.

The studied facility is one of the few in Greece because turkey production and health, face several problems and many side factors should be met. Additionally, the market for turkey products in Greece is not widespread. In recent years, turkey breeding in Greece has been on the decline, as many producers are no longer able to meet the breeding costs (Stergiou,2016).

In general, turkeys are very sensitive and any change in environmental conditions can confuse them. Turkey production accounts for 15% of European poultry meat[6].

For the roof and surroundings, polyurethane panels of 5mm thickness were used. The floor of the poultry house is assumed to be laid on a concrete slab with a layer of wood chips and is directly in contact with the ground. There is a long window close to the roof (20 mm x 570 mm) at the long sides of the building and a door (~ 120 mm x 200 mm) made of a polyurethane panel of the same thickness as the rest of the facility.

In the table below are presented the main thermophysical and geometrical properties of the envelope of the A1 poultry house.

*Table 8: The main thermophysical and geometrical properties of the envelope of the A6 poultry house.*

| Building components | | Area [$m^2$] | U-value [$W\ m^{-2}\ K^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 33 | 0.43 |
| Vertical structural elements | Wall | 106.47 | 0.73 |
| | Window | 2.28 | 2.0 |
| | Door | 2.40 | 0.73 |
| Horizontal (floor) | Floor | 33 | 0.8 |

No additional data was provided on ventilation and heating systems at the time the data was collected.

The building's thermal capacity was calculated at 138m W/K, under 5.2 air changes per hour and a winter outdoor design temperature of 0°C the peak building heat loss was calculated at 5.96 kW. Those are the needs that have to be met in order to reach the mean set point temperature of no less than 18 °C. Finally, no energy logs were delivered.

An overview of the key elements and outcomes of the Greek cases is shown in Table 9:

[6] https://www.coe.int/t/e/legal_affairs/legal_co-operation/biological_safety_and_use_of_animals/farming/Rec%20Turkeys.asp

*Table 9: Key elements and outcomes of the Greek cases.*

| Case identifier | Type of farm | Location/ Climate Zone | No. of housed animals | Peak building heat losses [kW] |
|---|---|---|---|---|
| **A1** | Poultry farm for meat production | Arta/ B | 20.000 | 189.66 |
| **A2** | Laying hens | Arta/ B | 800 | 11.18 |
| **A3** | Poultry Broiler | Arta/ B | 12.000 | 112.73 |
| **A4** | Laying hens | Megara/ B | 2000 | 24.21 |
| **A5** | Laying hens | Megara / B | 500 | 4.69 |
| **A6** | Turkeys farm for meat production | Agios Dimitrios, Attiki/ B | 120 | 5.96 |

# 4 THE ITALIAN CASES

Following the aggregated data concerning the case of the farms located in Italy are presented. The 4 cases are located in climate zone[7] "E" and refer to different cases of dairy cattle and fattening pig farms. In the cases of fattening pig farms, estimates had to be made for structural elements and building position. Table 10 below summarizes the basic elements of the case studies collected in Italy:

*Table 10: Basic elements of the case studies collected in Italy.*

| Case identifier | Type of farm | No. of housed animals | Location | Final product per year | Total Surface area [$m^2$] |
|---|---|---|---|---|---|
| **B1** | Dairy Cattle | 450 milking cows + 65 dry cows + 600 replacement heifers | Bologna | 4600 tons of milk | 3390 |
| **B2** | Fattening Pigs | 2970 animals | Mirandola | 4500 pigs | 5000 |
| **B3** | Fattening Pigs | 4000 animals | Mirandola | 5000 pigs | 2000 |
| **B4** | Dairy Cattle | 70 milked cows + 20 dry cows + replacement heifers | Budrio | 850 tons of milk | 1350 |

## 4.1 The "B1" Italian case

The case of "B1" corresponds to a case of a dairy cattle farm of 1115 cows and 4500 tones of milk final production per year. We have no data for the building structure. An open side – with steel columns-so no thermophysical properties of the overall envelope are calculated. The overall energy cost of this case is 150,805€ of which 108,000€ is spent on Diesel, 4.335€ for natural gas and 38,370€ for electricity. It is known that there is already a PV system of 200 kWp installed on a rooftop and is scheduled to expand this installation. The farm is located near Bologna.

Local climate conditions seem to favor PV-electricity installations but there are no further logs to evaluate alternative renewable options. The full set of yearly (2023) energy log data presented in the following graphs indicates that the load of energy consumed monthλυ has small fluctuations depending on the season. This suggests that renewable solutions that offer a fixed electrical charge are most desirable:

[7] https://www.celsiuspanel.it/en/climatic-zones/

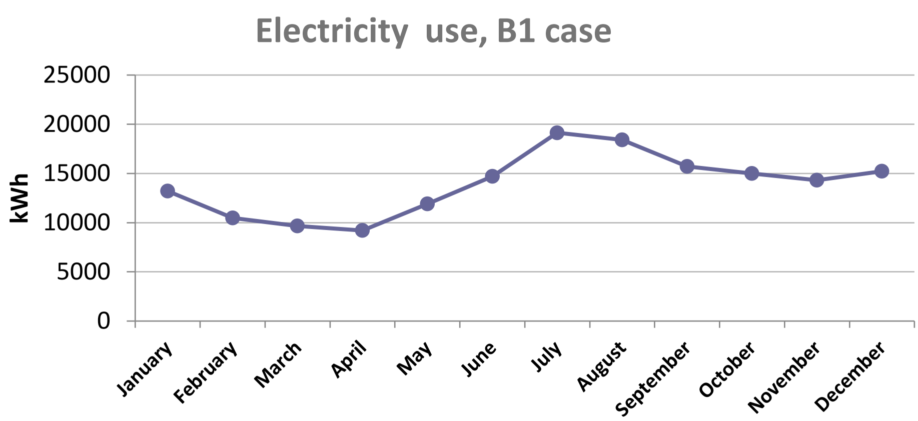



*Figure 9: Electrical energy consumption during 2023 for farm B1.*

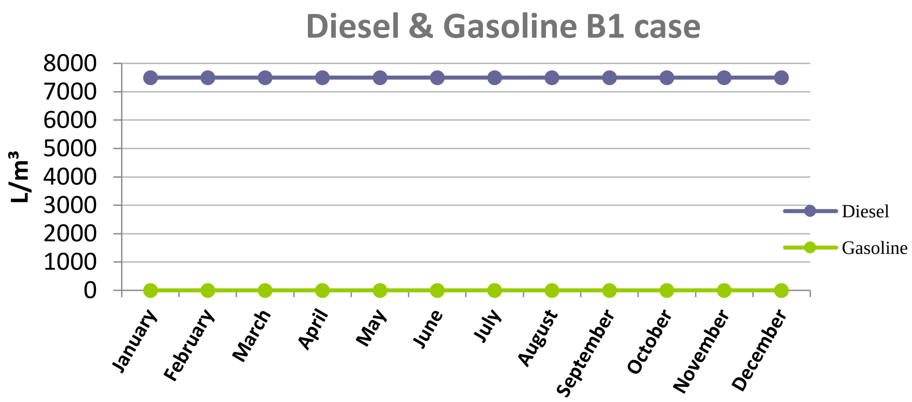



*Figure 10: Diesel and gasoline energy consumption during 2023 for farm B1.*

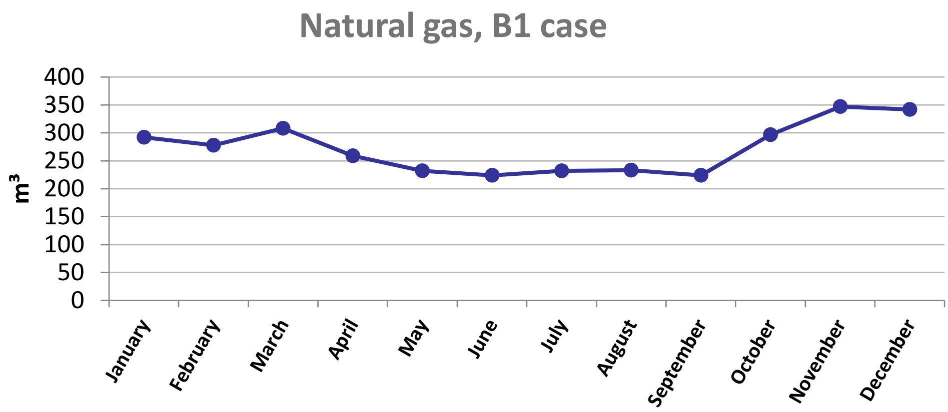
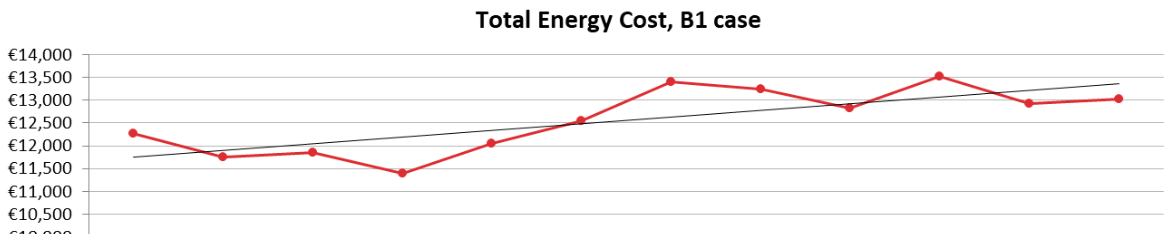



*Figure 11: Natural gas consumption during 2023 for the farm B1.*




| | January | February | March | April | May | June | July | August | Septembe r | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL ENERGY COST | € 12,267 | € 11,757 | € 11,850 | € 11,404 | € 12,054 | € 12,555 | € 13,399 | € 13,237 | € 12,825 | € 13,516 | € 12,916 | € 13,020 |

*Figure 12: Total energy cost for the case B1.*

## 4.2 The "B2" Italian case

The case B2 corresponds to a fattening pig farm. The total surface area of the installation is 5000m$^2$ (~ 20 m x 250 m, and a height of 2.8 m). The seasonal size of the unit in terms of animal capital is 2970 pigs. The installation is prefabricated with concrete pigsty with reinforced concrete panels with thermal break measuring 240 x 340 cm, 30 cm thick, insulated for thermal insulation with sintered polystyrene with the addition of class E self-extinguishing closed-cell graphite, bi-ribbed tiles with closed heads on the T-shaped suction walls installed at dry and self-supporting reinforced concrete domes

We estimate that the building has 1 metal sliding door (~ 164 mm x 225 mm). No other data was given on the layout of the facility, therefore additional estimations were made. The facility is located at Mirandola.

*Table 11: Main The thermophysical and geometrical properties of the envelope of the B2 case.*

| Building components | | Area [m²] | U-value [W m⁻² K⁻¹] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 4000 | 0.37 |
| | Rooflights | | |
| Vertical structural elements | Wall | 1476 | 0.29 |
| | Window | 32 | 0.22 |
| | Door | 3.69 | 0.73 |
| Horizontal (floor) | Floor | 5000 | 0.94 |

The building thermal capacity was calculated at 6618 W/K, under 2,97 air change per hour and winter outdoor design temperature or -2°C the peak building heat losses were calculated at 450.51 kW. Those are the needs that have to be met to reach the mean set point temperature of no less than 20 °C.

The energy needs of the facility are covered using electricity. No other energy source is mentioned. Figure 13 and Figure 14 present, respectively, the total energy use (37475 kWh) and energy cost (7786€) for a one-year period (2022). No use of renewable sources is mentioned.

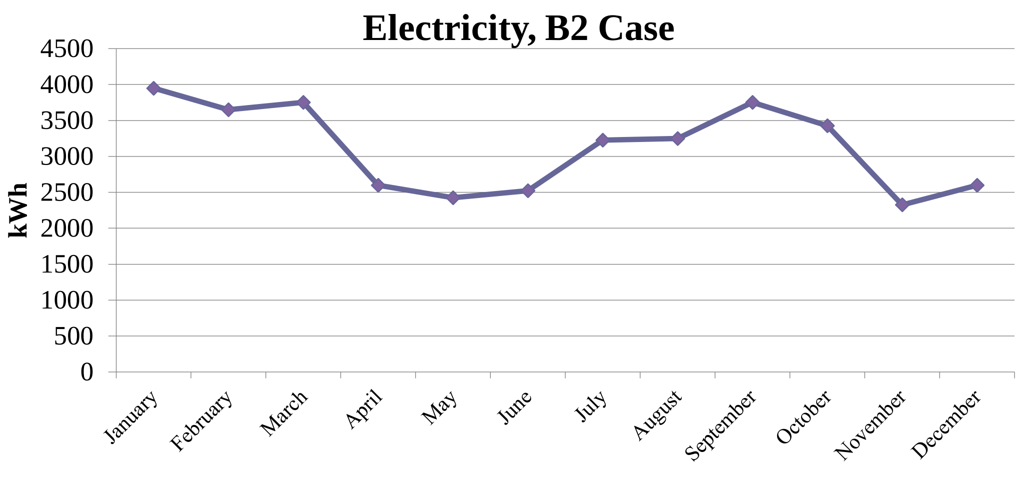



*Figure 13: Electrical energy consumption during 2023 for farm B2.*

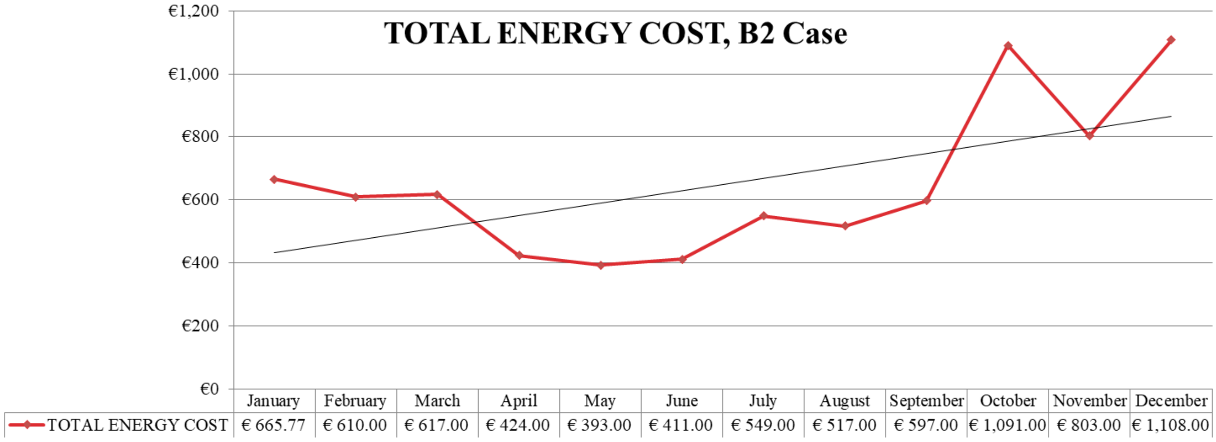



*Figure 14: Total energy cost for the case B2.*

No additional data was provided on ventilation and heating systems at the time the data was collected.

Near to the facilities there is a geothermal field and biomass availability. There is also the possibility of extending the photovoltaic system that already occurs at the installation. Although due to the moderate PV index of 4 a system of renewable sources from different forms of supply seems a possible sustainable energy solution.  No further energy log information was given.

## 4.3 The “B3” Italian case

The B3 case corresponds to a pig farm for meat production.  The total surface area of the installation is 2000 $m^2$ (~ 10 m x 200 m and height of 2.8 m).  The seasonal size of the unit in terms of animal capital is 4000 pigs. The covering of the building is a prefabricated concrete pig barn of 15 cm thickness.

The building has 1 metal sliding door (~ 104 mm x 225 mm). No other data was given on the layout of the facility; therefore, estimations were made. The facility is located at Mirandola.

The energy needs of the facility is using electricity. No other energy source is mentioned. Figure 15 and Figure 16 are presented, respectively, the total energy use (31725 kWh) and energy cost (8983€) for one year period (2023). No use of renewable sources is mentioned.

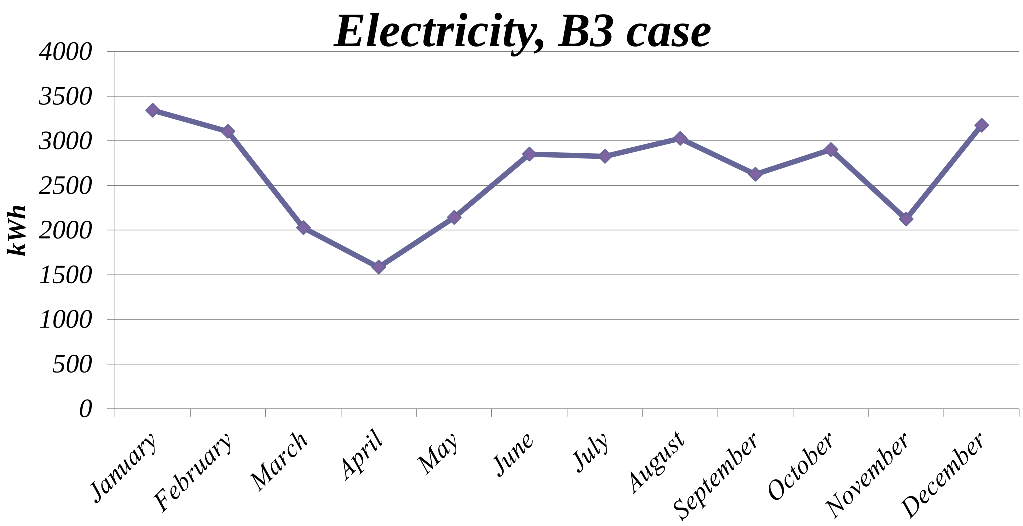



*Figure 15 Electrical energy consumption during 2023 for farm B3.*

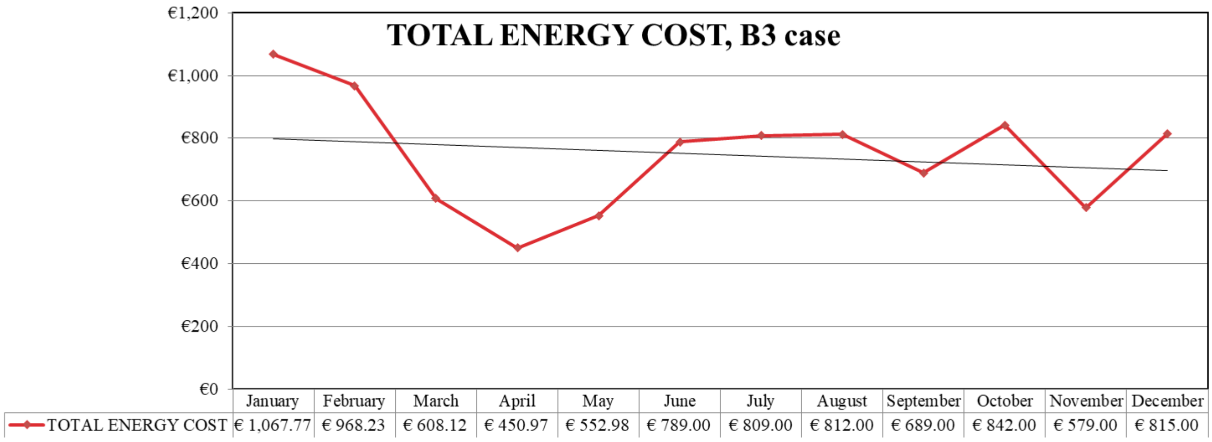



*Figure 16 Total energy cost for the case B3.*

The installation is made of prefabricated concrete 15 cm thick, and it has automatic windows and "roof chimneys" so an assumption of an uninsulated roof was made- other elements are not specified; therefore, assumptions were made. In Table 12 below the main thermophysical and geometrical properties of the envelope of the B3 pig farm are presented.

*Table 12: The thermophysical and geometrical properties of the envelope of the B3 case.*

| ***Building components*** | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 1350 | 2.5 |
| Vertical structural elements | Wall | 150 | 0.38 |
| | Window | 18 | 0.3 |
| | Door | 2.34 | 0.73 |
| Horizontal (floor) | Floor | 2000 | 0.9 |

No additional data was provided on ventilation and heating systems at the time the data was collected.

The building's thermal capacity was calculated at 5239 W/K, under 5 air change per hour and winter outdoor design temperature of -2°C the peak building heat losses were calculated at 320,59 kW. Those are the needs that have to be met in order to reach the mean set point temperature of no less than 20 °C.

Near to the facilities there is a geothermal field, while the owners of the farm estimate that biomass can be used as an alternative energy fuel with a smaller emission footprint. There is also the possibility of extending the photovoltaic system that already exists at the installation. No further information is given.

## 4.4 The "B4" Italian case

The last Italian case, "B4", is a case of a dairy cattle farm of 90 cows and 850 tons of milk final production per year. We have no data for the building structure. Open sides – with steel columns with double insulated metal sheets in the ceiling- no thermophysical properties of the overall envelope are calculated. No energy logs are reported, nor renewable energy sources is used. In the case of this small farm, a techno-economic analysis of the sustainability of a PV energy system would be helpful to record affordable energy solutions with a smaller carbon footprint.

An overview of the key elements and outcomes of the Italian cases is shown in Table 13[8]:

*Table 13: Key elements and outcomes of the Italian cases.*

| Case identifier | Type of farm | Location/ Climate Zone | No. of housed animals | Peak building heat losses [kW] |
|---|---|---|---|---|
| **B2** | Fattening Pigs | Mirandola/ E | 2970 | 450.51 |
| **B3** | Fattening Pigs | Mirandola/ E | 4000 | 320.59 |

[8] Results for dairy cattle farms are not presented, as these are open buildings, and the T3.4 toolset proved to be more suitable for simulating swine and poultry buildings, which are enclosed. A different approach and corresponding toolset would be required to generate valuable data for cattle farms.

# 5 THE BELGIAN CASES

The last section concerns the Belgium livestock farm cases. Belgium has four main climate zones: maritime, continental, Ardennes, and coastal [9]. Currently 4 different cases of pig broilers are presented, laying hens and broilers are all part of a local educational farm ecosystem.

All ILVO farm groups are located along the Burg. Van Gansberghelaan in Merelbeke, Belgium.

The climate profile of this region is described below.[10]

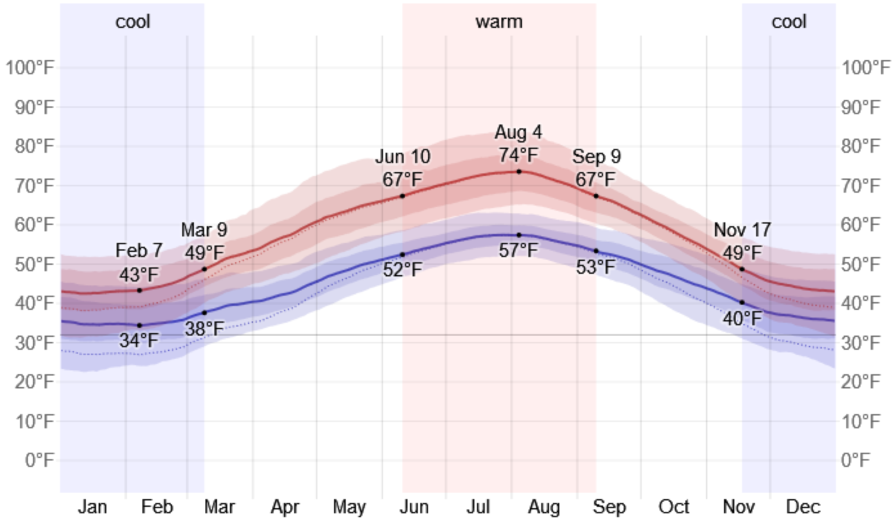



*Figure 17: The daily average high (red line) and low (blue line) temperature, in Merelbeke, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures.*

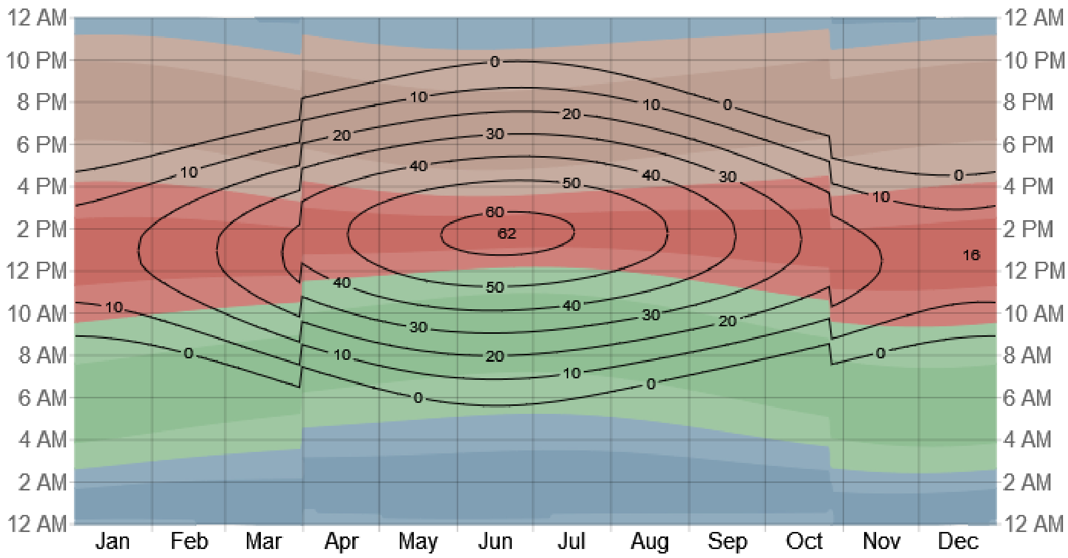



*Figure 18: Solar elevation and azimuth over the course of the year 2024. The black lines are lines of constant solar elevation (the angle of the sun above the horizon, in degrees). The background color fills indicate the azimuth (the compass bearing) of the sun. Orientation by color Blue:North, Green:East, Red:South, Pink:West.*

[9] http://dx.doi.org/10.1175/JAMC-D-21-0004.1

[10] Data extracted from https://weatherspark.com/y/49665/Average-Weather-in-Merelbeke-Belgium-Year-Round

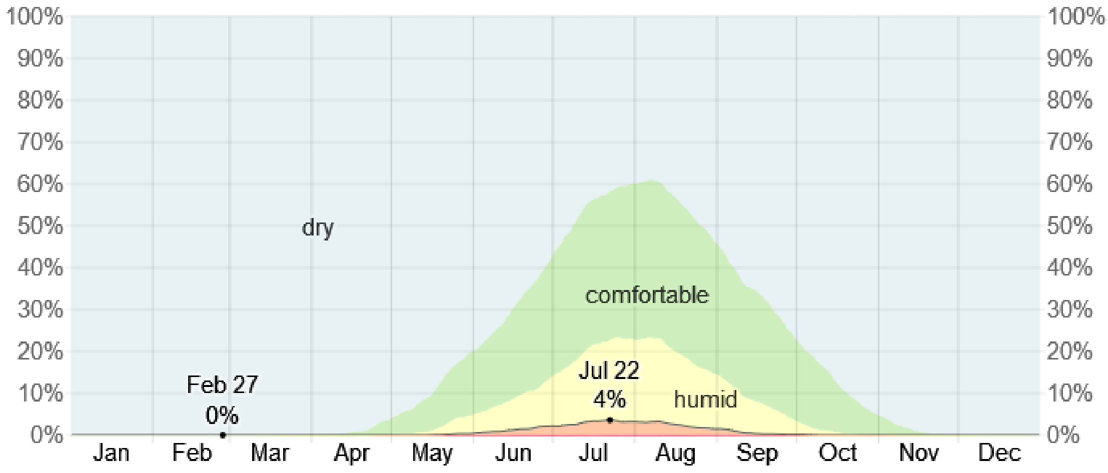



*Figure 19: The percentage of time spent at various humidity comfort levels, categorized by dew point.*

Table 14 below summarizes the basic elements of the Belgium case studies:

*Table 14: The thermophysical and geometrical properties of the envelope of the B3 case.*

| Case identifier | Type of farm | Seasonal unit size | Location | Final product per year | Total Surface area (m$^2$) |
|---|---|---|---|---|---|
| **C1** | Farrow to finish sow farm | 200 pigs | Scheldeweg | 3006 pigs, 469 fattening pigs and 52 breeding sows | 2914 |
| **C2** | Dairy farm | 140 lactating cows | Scheldeweg | 1.398.289 liters | 4250 |
| **C3** | Broiler | 2400 | Burg | 8690 broilers | 465.9 |
| **C4** | Laying hens | 896 laying hens | Burg | 132510 eggs and 842 laying hens | 400 |
| **C5** | Broiler | 1800 | Burg | 6536 | 760 |

## 5.1 The “C1” Belgium case

The case of C1 corresponds to a case of farrow to finish sow farm of 200 pigs, corresponding to 120 fattening pigs and 80 sows.

Below is the topography and a visual impression C1 farm exterior:


*Figure 20: Topography of farm C1.*

*Figure 21: Picture of side external wall of fattening pig compartment at C1 case.*

Local climate conditions seem to favor PV-electricity installations but there are no further logs to evaluate alternative renewable options. The full set of a 10-month period (06.2023 to 06.2024) energy log data is presented in the following graphs.

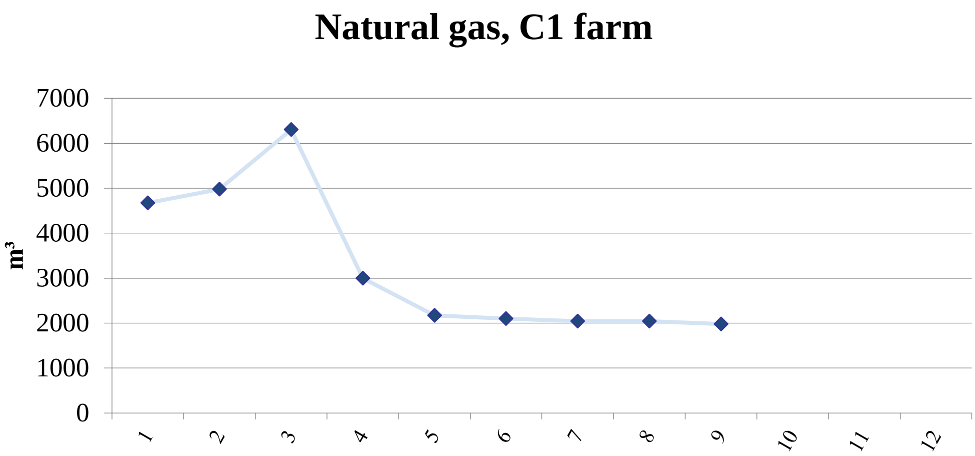



*Figure 22: Natural gas consumption during 2023 for farm C1.*

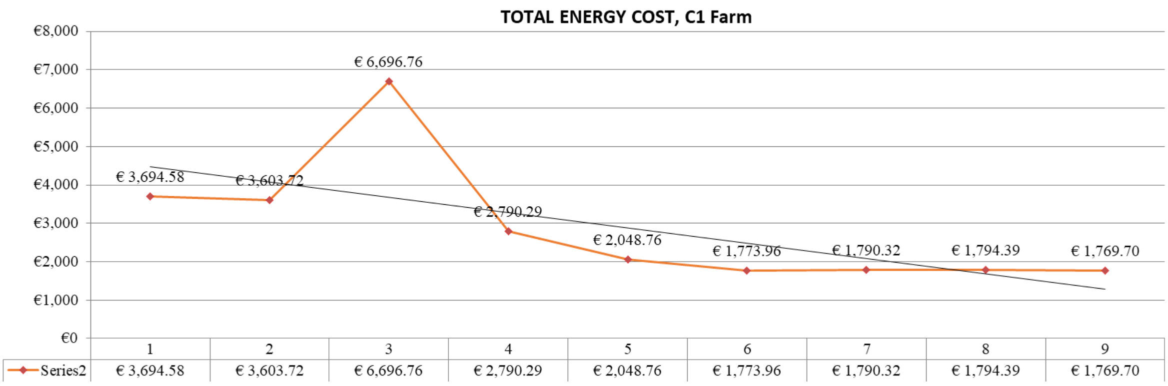



*Figure 23: Natural gas cost for 2023, C1 case.*

Natural gas prices were estimated[11] and there was no separate electricity meter at the installation therefore no relevant data was available.

The case with the reference name C1 corresponds to a fattening pig farm. The total surface area of the installation is 2914 m$^2$. Currently will be calculated the thermal capacity and the peak building heat loss for the pregnant sow's department that accommodates an average of 80 sows. This facility (12 m x 18 m x 2.8 m) is built with concrete walls and bricks and the ceiling uses wooden frames and asbestos corrugated sheets. There are glass blocks [(0.8x2) m x3] windows as can be seen in Figure 21, and roof ventilators. We assume that the floor is insulated.

We assume that the main building axis has an east-west orientation with its longest dimensions having a north-south orientation.

We estimate that the building has 1 metal sliding door (~ 164 mm x 225 mm) 40 mm thick.

[11] https://dashboard.vreg.be/report/DMR_Prijzen_gas.html

*Table 15: Main thermophysical and geometrical properties of the envelope of the C1 case.*

| Building components | | Area [m²] | U-value [W m⁻² K⁻¹] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 216 | 0.25 |
| Vertical structural elements | Wall | 145.1 | 0.94 |
| | Window | 4.8 | 5.1 |
| | Door | 3.7 | 0.82 |
| Horizontal (floor) | Floor | 216 | 0.27 |

The building's thermal capacity was calculated at 276 W/K, under 3.3 air change per hour and with winter outdoor design temperature of -4°C the peak building heat loss was calculated at 32.96 kW. The set point temperature was set at 33°C equal to the Equivalent Temperature Index of the Sows (ETIS)[12].

At the facility, there is a PV installation and the potential for additional use of biomass and wind power.

## 5.2 The "C2" Belgium case

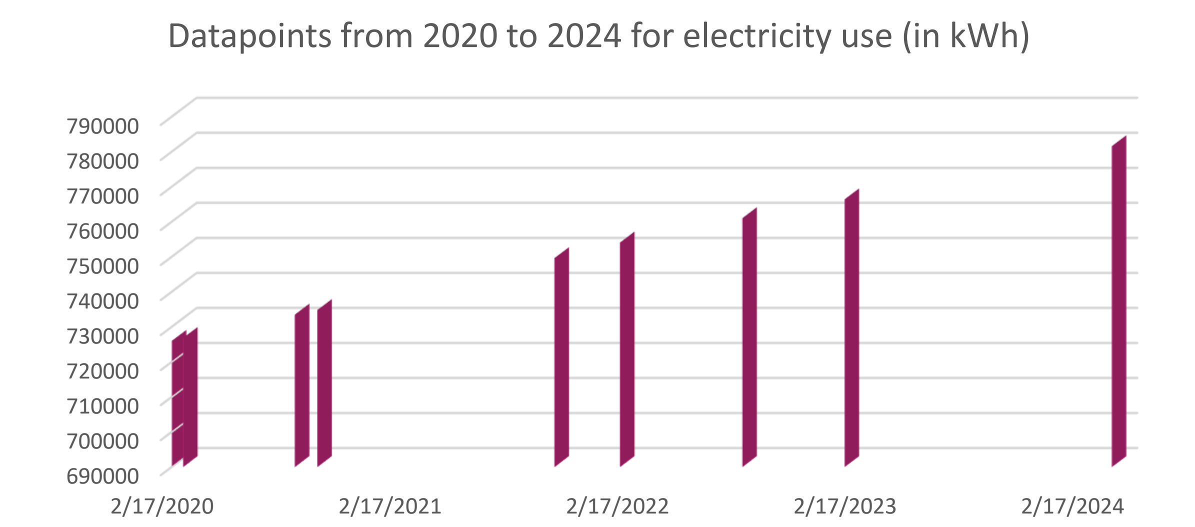
The case of "C2" corresponds to a case of a dairy cattle farm of 140 cows and a yearly production of 1,398,289 (2023 data). We have no data for the building structure.

The farm installation has a wire mesh against birds and motorised windshields and the ceiling has asbestos-free corrugated sheets and PUR isolation (4cm thick) asbestos-free corrugated sheets with PUR isolation (4cm) and open ridge "windows" which provide two channels of light (double-walled polycarbonate).

Local climate conditions seem to favour PV-electricity installations and farmers suggest that biomass could additionally use on the spot.  There are no further logs to evaluate current and alternative renewable options.

There are no yearly records of energy consumption in the facility. Below are presented spotted energy records of monthly electrical consumption for several months during the period 2020 to 2024. The records refer to different months within the years. Several of those have taken place in the Winter months so we could relatively safely conclude that over the years the energy demands on the farm in question seem to increase - we assume that the volume of the living element is held constant:

[12] https://doi.org/10.3390/ani11051472




| | 2/17/2020 | 3/6/2020 | 9/1/2020 | 10/7/2020 | 10/22/2021 | 2/4/2022 | 8/19/2022 | 1/30/2023 | 4/3/2024 |
|---|---|---|---|---|---|---|---|---|---|
| Series1 | 726007 | 726827 | 733497 | 734798 | 749623 | 754078 | 761019 | 766401 | 781589 |

*Figure 24: Datapoints from 2020 to 2024 for electricity energy use (in kWh) at C2 case.*

Finally, no yearly energy data logs are available.

## 5.3 The "C3" Belgium case

The case of C3 corresponds to a broiler farm. In a year the total yearly population of broilers is estimated at 8690 and the farm's volume is 2400 (95 cages x 30 broilers). The following figures present the monthly broiler population in 2023.

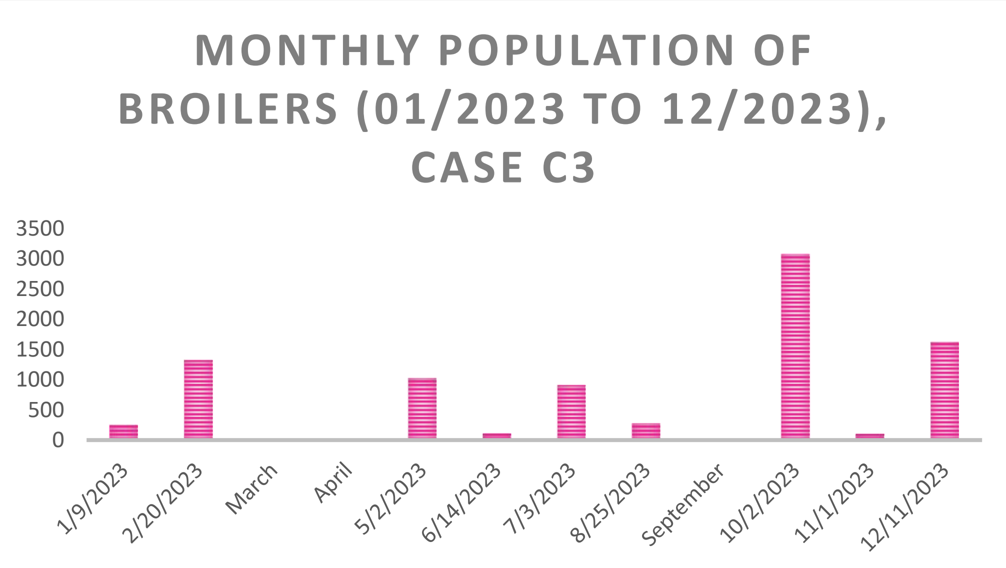



*Figure 25: Monthly population of broilers (01/2023 to 12/2023) for C3.*

The total surface area of the installation is 465.9m$^2$ (47m x 9.9 m and height of 2.8 m). No other data was given on the layout of the facility.

The wall is made of single autoclaved aerated concrete (AAC)[13,14]. For the roof is used isolated (PIR) and plates of AAC, of unknown thickness. The floor of the poultry house is assumed to be laid on a concrete slab directly in contact with the ground. Lastly, there are ~48 small PVC windows (60 cm x 30 cm) and two-door openings (4.18 m²). Assumed that the doors are made of polyurethane panel (5 mm thickness).

Table 12 presents the main thermophysical and geometrical properties of the envelope of the C3 poultry house as calculated under the available data gathered.

*Table 11: Main thermophysical and geometrical properties of the envelope of the C3 case.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 465.9 | 0.19 |
| Vertical structural elements | Wall | 305.82 | 1.89 |
| | Window | 8.64 | 5.1 |
| | Door | 4.18 | 0.43 |
| Horizontal (floor) | Floor | 465.9 | 0.27 |

The building's thermal capacity is calculated at 863 W/K, under 3.7 air change per hour and winter outdoor design temperature or -4°C the peak building heat losses are calculated at 53.77kW. Those are the needs that have to be met to reach the mean set point temperature of no less than 20 °C.

No additional data was provided for the ventilation. For heating, an absorption heat pump (ROBUR GAHP) and finned tubes are used (to achieve a temperature window of 35°C to 20°C over 6 weeks) and a gas boiler for the winter period is used. Below the measured electricity used by heating lamps (kWh) for 2023 is presented. No additional energy logs were provided.

[13] https://www.jescae.com/index.php/jtie/article/view/967
[14] https://doi.org/10.17559/TV-20200218194755

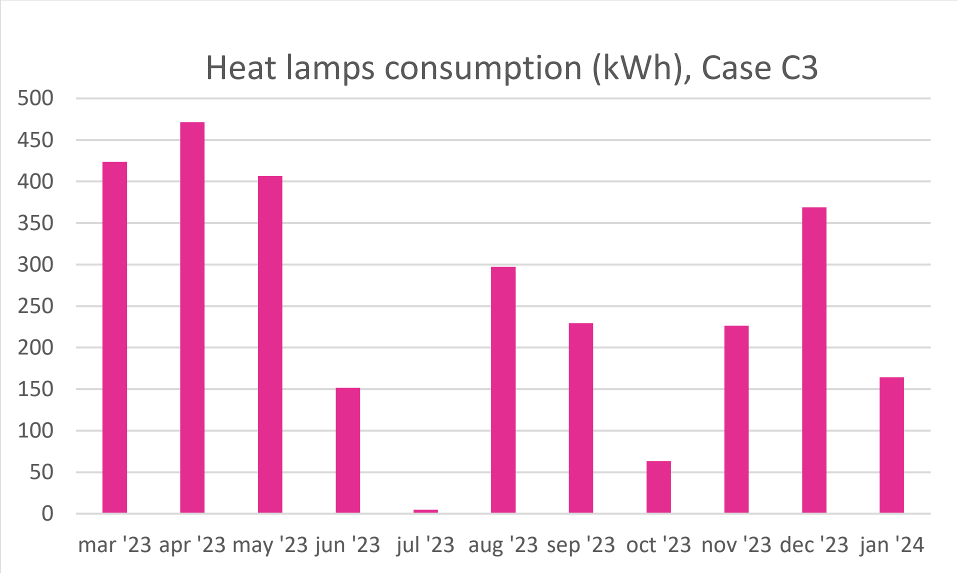



*Figure 26: Heating lamps consumption (kWh) from 03/2023 to 01/2024 for case C3.*

## 5.4 The "C4" Belgium case

C4 case refers to a laying hens farm with a yearly volume of 896 hens, yielding a yearly production of 132.510 eggs. The total surface area of the installation is 400m$^2$ (57 m x 7 m x 2.8 m), The main building axis has an east-west orientation with its longest dimensions having a north-south orientation. No specific data was given on the layout of the facility.

As before (case C3) the wall is made of autoclaved aerated concrete (AAC). The roof is insulated with polyisocyanurate (PIR) rigid foam and plates of AAC, of unknown thickness. The floor of the poultry house is assumed to be laid on a concrete slab directly in contact with the ground. Lastly, there are 6 small PVC windows (60 cm x 30 cm) and two door openings (4.18 m²). Assumed that the doors are made of polyurethane panel (5 mm thickness).

Table 16 presents the main thermophysical and geometrical properties of the envelope of the C4 case, as calculated under the available data gathered and the estimations made.

*Table 16: Main thermophysical and geometrical properties of the envelope of the C5 case.*

| Building components | | Area [m$^2$] | U-value [W m$^{-2}$ K$^{-1}$] |
|---|---|---|---|
| Orientation | Type | | |
| Horizontal (covering) | Roof | 400 | 0.19 |
| Vertical structural elements | Wall | 353.1 | 1.89 |
| | Window | 1.08 | 5.1 |
| | Door | 4.18 | 0.43 |
| Horizontal (floor) | Floor | 400 | 0.27 |

No additional data was provided for ventilation and heating systems at the time the data was collected.

The building thermal capacity was calculated at 874 W/K, under 2 air change per hour and winter outdoor design temperature or -2°C the peak building heat loss was calculated at 38.86 kW. Those are the needs that have to be met to reach the mean set point temperature of no less than 20 °C.

No additional data was provided for ventilation. For heating an absorption heat pump (ROBUR GAHP), finned tubes (18°C to 20°C), and heating lamps are used. Below is presented the measured electricity consumed by heating lamps (kWh) for a 10-month period in 2023:

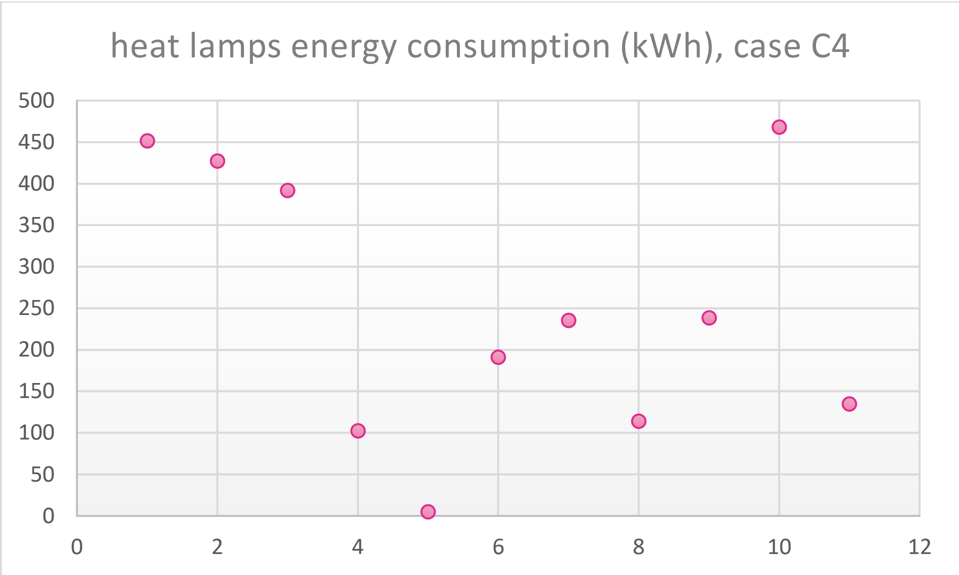



*Figure 27: Heating lamps consumption (kWh) from 10 month-period.*

At the C4 installation is used natural gas. For the year 2023 was consumed 114.464 kWh corresponding to a total cost of 9,431€. Below is presented the yearly consumption of this power source, starting from January 2023 to December 2023. No additional energy logs are provided.

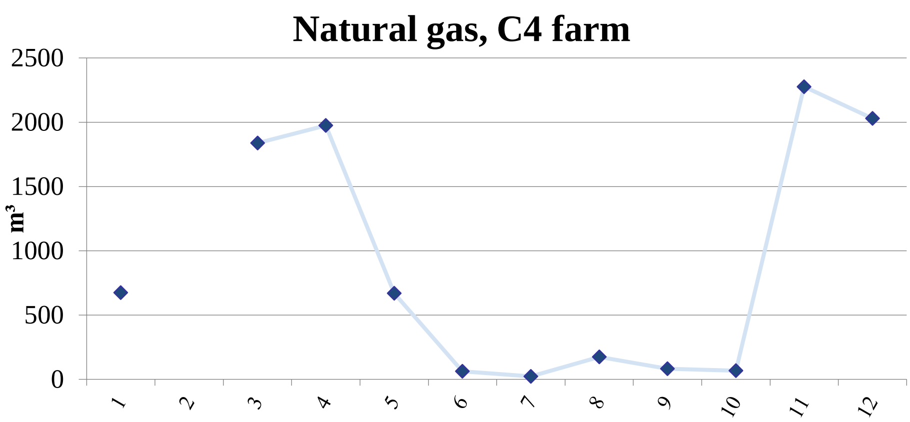



*Figure 28: Natural gas consumption (kWh) from a year (2023) period in case C4.*

## 5.5 The "C5" Belgium case

C5 case refers to a laying hens farm with 1800 broilers with a yearly production of 6536 broilers. The total surface area of the installation is 760 $m^2$ (50.7 m x 15 m x 2.8 m). As in previous cases, the main building axis has an east-west orientation with its longest dimensions having a north-south orientation. No specific data was given on the layout of the facility.

The wall of the current installation is made of bricks and concrete plate. The ceiling is made of metal plates and polyurethane plates and the unused attic space was renovated and isolated (2022). The ceiling is considered a horizontal insulated element. Lastly, there are 2 small windows (~ 115 mm x 115 mm) and 1 door (2.09 $m^2$). It was assumed that the windows are single glass, and the door is made of polyurethane panel (5mm thickness).

Table 17 presents the main thermophysical and geometrical properties of the envelope of the C5 case, as calculated under the available data gathered and the estimation that had to be made.

*Table 17: Main thermophysical and geometrical properties of the envelope of the C4 case.*

| Building components | | Area [$m^2$] | U-value [W $m^{-2}$ $K^{-1}$] |
|---|---|---|---|
| Orientation | Type | | |
| Horizontal (covering) | Roof | 760 | 0.31 |
| Vertical structural elements | Wall | 363.2 | 0.55 |
| | Window | 2.65 | 5.1 |
| | Door | 2.09 | 0.43 |
| Horizontal (floor) | Floor | 760 | 0.27 |

No additional data was provided for ventilation and heating at the time of the data collection.

The building thermal capacity was calculated at 655 W/K, under 3 air changes per hour and winter outdoor design temperature or -4°C the peak building heat loss was calculated at 49.78 kW. Those are the needs that have to be met to reach the mean set point temperature of no less than 20 °C.

In the facility, 2 gas boilers for hot water (via finned tubes) and 4 heat lamps are used. No additional energy data are available.

An overview of the key elements and outcomes of the Belgian cases is shown in Table 18[15]:

[15] Results for dairy cattle farms are not presented, as these are open buildings, and the T3.4 toolset proved to be more suitable for simulating swine and poultry buildings, which are enclosed. A different approach and corresponding toolset would be required to generate valuable data for cattle farms.

*Table 18: Key elements and outcomes of the Belgian cases.*

| Case identifier | Type of farm | Location | No. of housed animals | Peak building heat losses [kW] |
|---|---|---|---|---|
| **C1** | Farrow to finish sow farm | Scheldeweg | 200 | 32.96 |
| **C3** | Broiler | Burg | 2400 | 53.77 |
| **C4** | Laying hens | Burg | 896 | 38.86 |
| **C5** | Broiler | Burg | 1800 | 66.82 |

# 6 PARAMETRIC STUDIES FOR MAIN FARM TYPES

The objective of Task 3.4 was to develop a versatile numerical platform for simulating energy and resource flows in the livestock sector through livestock-specific case modelling. Specifically, the energy demand and production of the initial pilot farms are simulated using input data such as energy demand and production potential, the necessary thermal comfort for the animals, and indoor conditions.

The energy simulation model for the AUA poultry farm and the ILVO pig farm estimates indoor air temperature variations on an hourly basis. The simulator takes into account factors such as animal age, outdoor weather conditions, and the use of heat pumps, ventilators, and other equipment.

In this section, we analyze the different energy needs of the system studied at the ILVO farm (Case A) and the AUA farm (Case B) after modifications to specific elements of each farm, in order to assess their impact on the overall system.

## 6.1. A Parametric study for the pilot farm in Belgium

Pilot farm in Belgium, herein Ilvo farm, corresponds to a Pig Campus of Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) in Merelbeke, Belgium. Pig production on this farm is carried out with a closed cycle, meaning that all the pig production stages -from insemination to fattening- are performed on the same farm. Consequently, the Pig Campus is designed to accommodate pigs of various ages and weights and is equipped with the necessary facilities to meet their diverse needs. The focus of the modelling activity is one of the fattening compartment rooms, which is considered to have a very important role at the facility.

The analysis will be carried out in the same room under the following conditions:

| | | | |
|---|---|---|---|
| ILVO pig farm | Different animal numbers (**decrease by 21.88% and increase by 21.88%)** | Different u-value at the roof element, corresponding at a higher value and therefore an inadequate element in terms of insulation | ***Lower ventilation capacity*** |
| AUA poultry farm | Animal population growth by 10% | Higher u-value of the floor and the roof | Lower u-value of the floor and the roof |

### Different animal numbers (-21.88 and +21.88%)

The envelope of the fattening compartment analysed corresponds to an element for which all the actual physicochemical conditions and geometric characteristics have been studied. In this case, we assumed that the number of animals in the room decreased by 21.88% and increased by 21.88% respectively. All other elements remain unchanged.

**Higher animal population**

Following is a study of the trends of air temperature, sensible heat loads, specific humidity and latent heat loads of monitored values in Ilvo, in case of a larger animal population in the same room and indoor air temperature, outdoor air temperature and indoor Relative humidity (°C) at the required temperature set point in correlation with the age of the animals during the same period under a 21.88% decrease in the population of animals in the room. As recorded in the diagrams below, the increased animal population causes insufficient ventilation and the need for cooling the room for a longer period of time.

**Higher animal population**

Similarly, to the above, the results are reflected, in the 21.88% increase in the population of the pigs in the same room under the same conditions. The overall results illustrate the importance of the role played by the number of living beings in the study room system as it greatly affects the thermal loads.

## Different u-value at the roof element

The building is normally thermally insulated using polyurethane panels in the external walls and the roof. In this case, we study the system with the assumption of the deficit isolation of the horizontal elements of the room, roof & floor - the values are reflected in Table 19, below.

*Table 19 Thermophysical properties estimation of the considered fattening compartment studied of the Ilvo farm*

| **Building components** | | $\mathbf{U-value}$ |
|---|---|---|
| **Orientation** | **Type** | $[\mathbf{W\,m^{-2}\,K^{-1}}]$ |
| Horizontal (covering) | Ceiling | 1.86 |
| | Roof | 0.78 |

We used the model that has been produced at T3.4 for this specific system using the new values for the roof element and the results of the analysis are shown below.

The system appears to be less affected by this change compared to the previous case study, as empirically expected. During the winter months, the new thermodynamic system seems to be lacking in terms of satisfying the needs of the living population - here pigs.

## Lower ventilation capacity

The last case study illustrated the effectiveness of the lower maximum ventilation capacity by 30%, of the fan used for ventilation at the fattening department. Below are the results of the analysis, where the ineffective ventilation rate is also evident. A large deviation from the maximum ventilation capacity was chosen to demonstrate the strong variation in thermal load within the system under consideration.

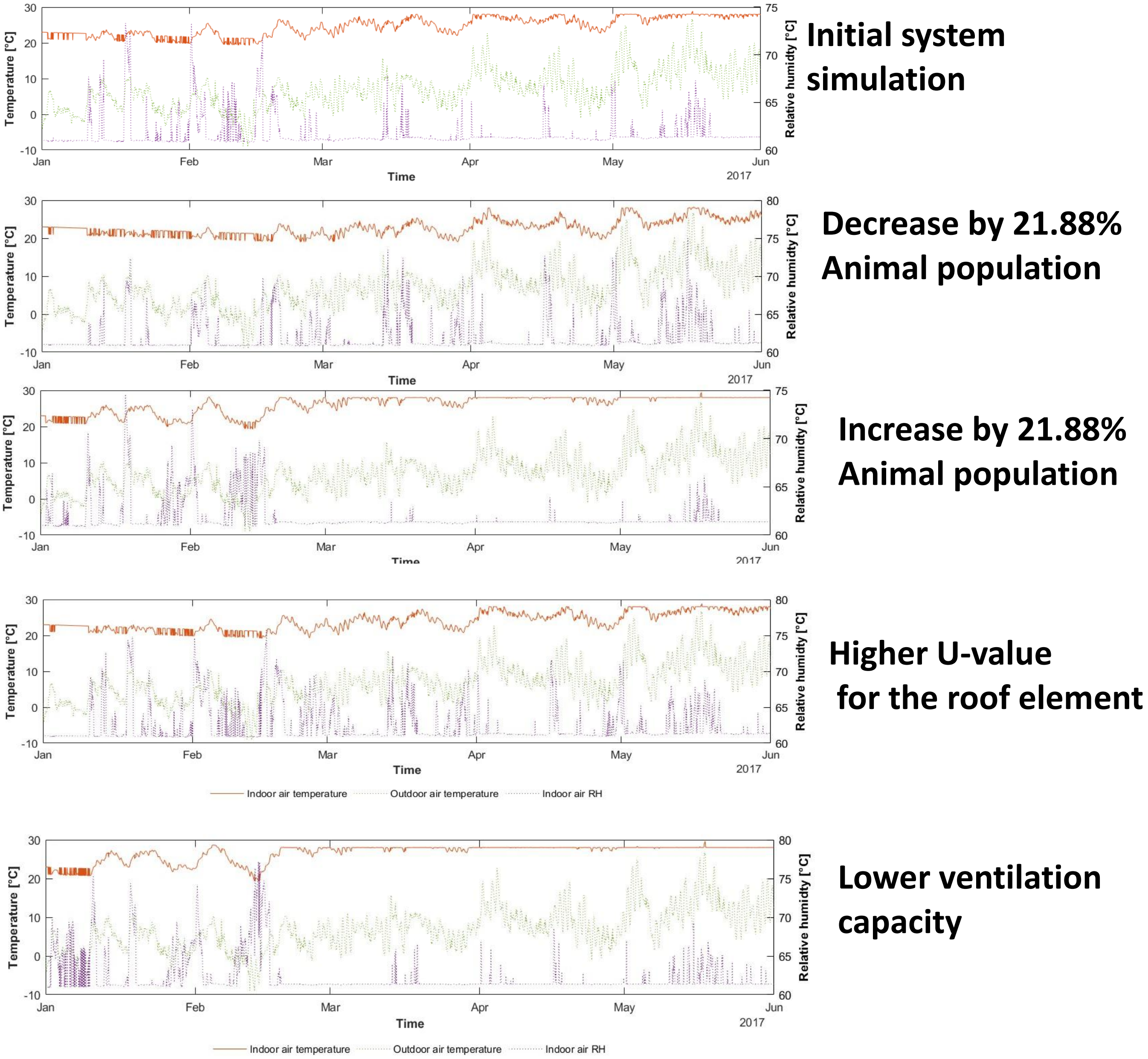



*Figure 29 ILVO farm - Indoor air temperature, outdoor air temperature and indoor Relative humidity (oC) at the required temperature set point.*

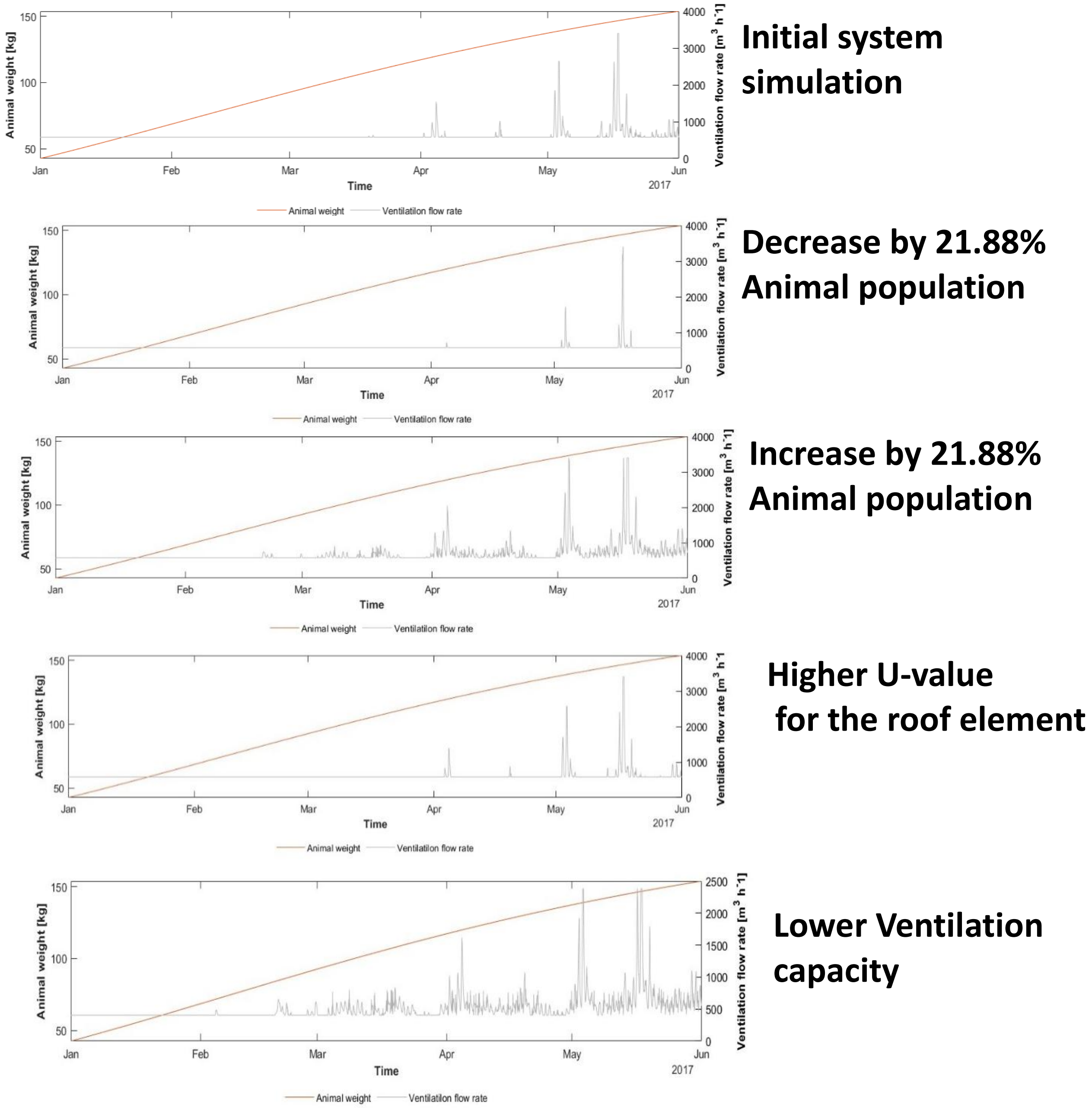



*Figure 30 ILVO farm – Ventilation flow rate via the age of the animals during the same period*

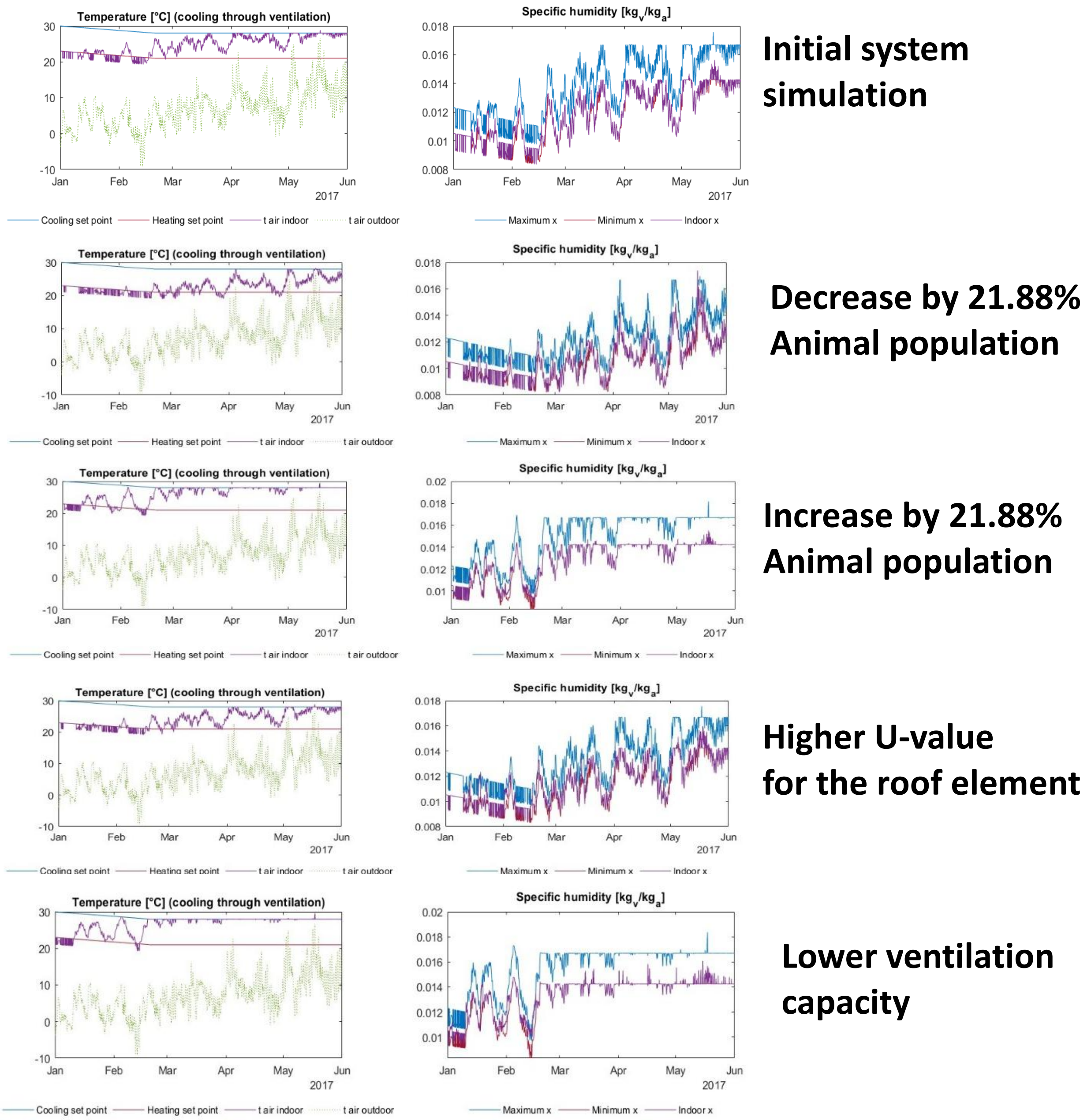



*Figure 31 Trends of air temperature and specific humidity of monitored values in Ilvo farm, at all studied cases*

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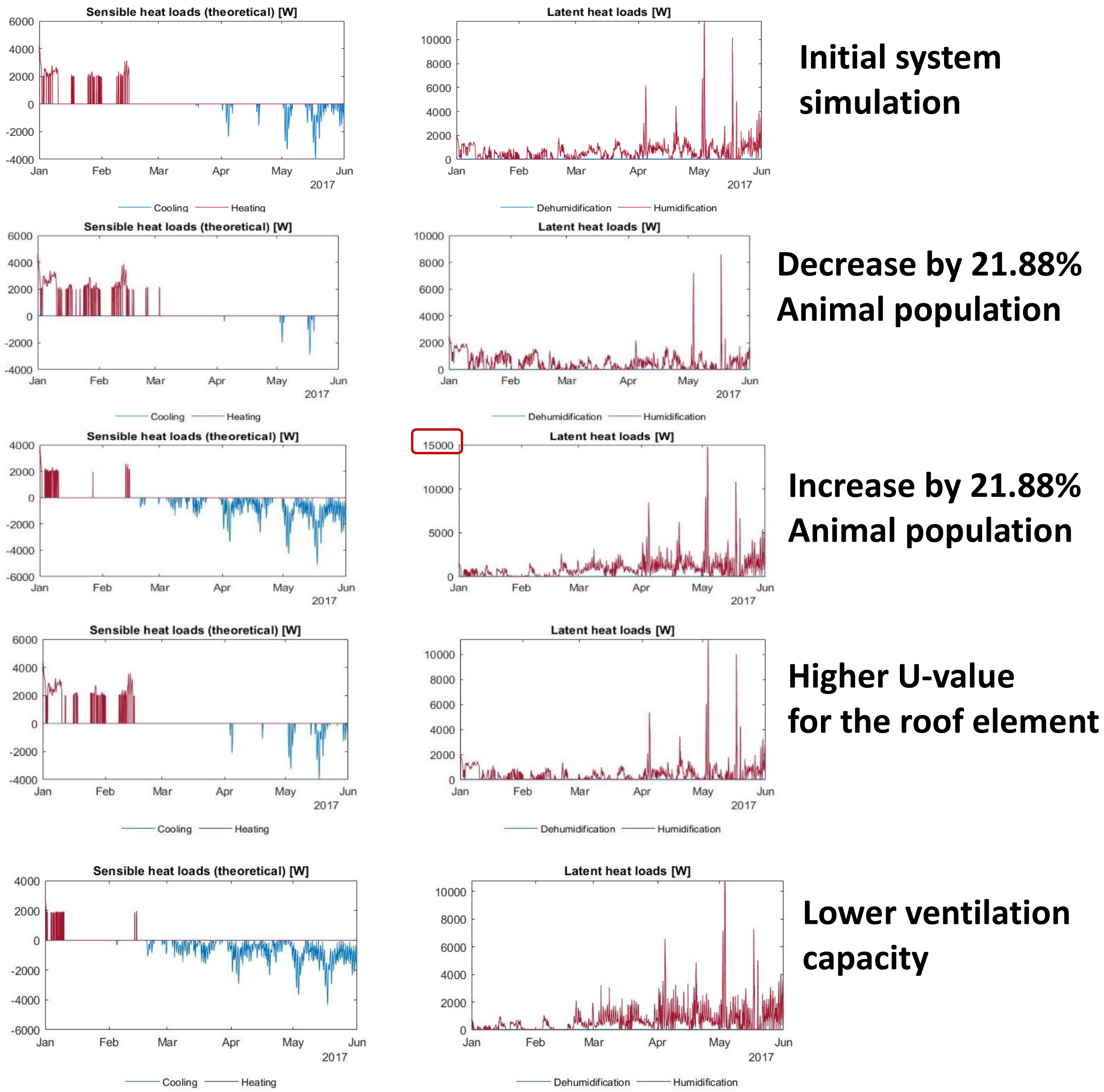


*Figure 32Trends of sensible heat loads and latent heat loads of monitored values in Ilvo farm during a typical meteorological year.*

# 6.2. B Parametric study for the pilot farm in Greece

The educational and experimental farm poultry farm for egg production has been established at the Agricultural University of Athens (AUA) for more than 70 years. The poultry house was characterized both thermophysically and geometrically to gather all the necessary input data for the AUA farm-specific energy simulation model.

In this case, we examine the variations that arise in the original model under extreme conditions that concern individual elements of the model, specifically.

Case A. Insufficient insulation in the floor and roof

Case B. lack of insulation on the floor and the roof but also in the room window

The following table presents the u values as calculated for the elements that are varied in this study [Table 20]. All other elements remain constant as they were initially studied.

*Table 20:Thermophysical properties estimation of the envelope of the AUA poultry house.*

| **Building components** | | $\mathbf{U-value}$ $[\mathbf{W\,m^{-2}\,K^{-1}}]$ | |
|---|---|---|---|
| **Orientation** | **Type** | | |
| Horizontal (covering) | Roof | 1.33 max | 0.19 min |
| Horizontal (floor) | Floor | 1.26 max | 0.16 min |

## Different (higher and lower cases) u-values of the floor and the roof

Different u-values of the structural elements concerning the roof and the floor of the room, where extreme values are selected.  Boundary conditions were selected, which concern deficient insulation, to study how these changes affect the system All the other parameters remain constant.

**Higher U-value for roof and floor**

As can be seen in the figures below, based on these changes made to the system, the living conditions of the population are not satisfied throughout the year as there are extreme values outside the temperature limits that must be met.

**Lower U-value for roof and floor**

## Population growth by 10%

Finally, we used the same model, assuming that the population of living beings throughout the study period is increased by 10%, where it is observed that the thermal loads created by the present arrangement and under the new condition do not act negatively on the system.

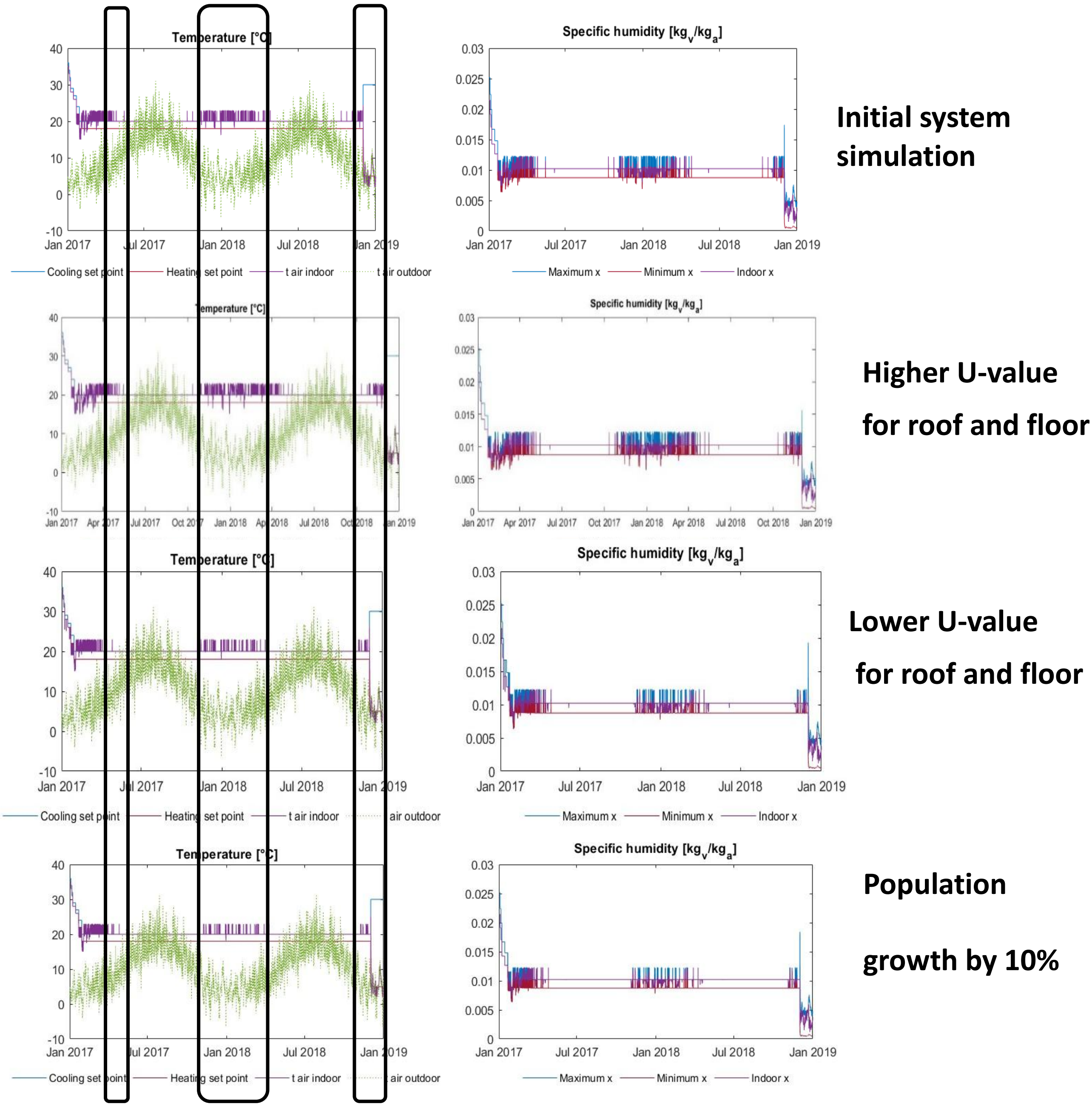


*Figure 33 Trends of air temperature and specific humidity of monitored values in AUA farm, at all studied cases*

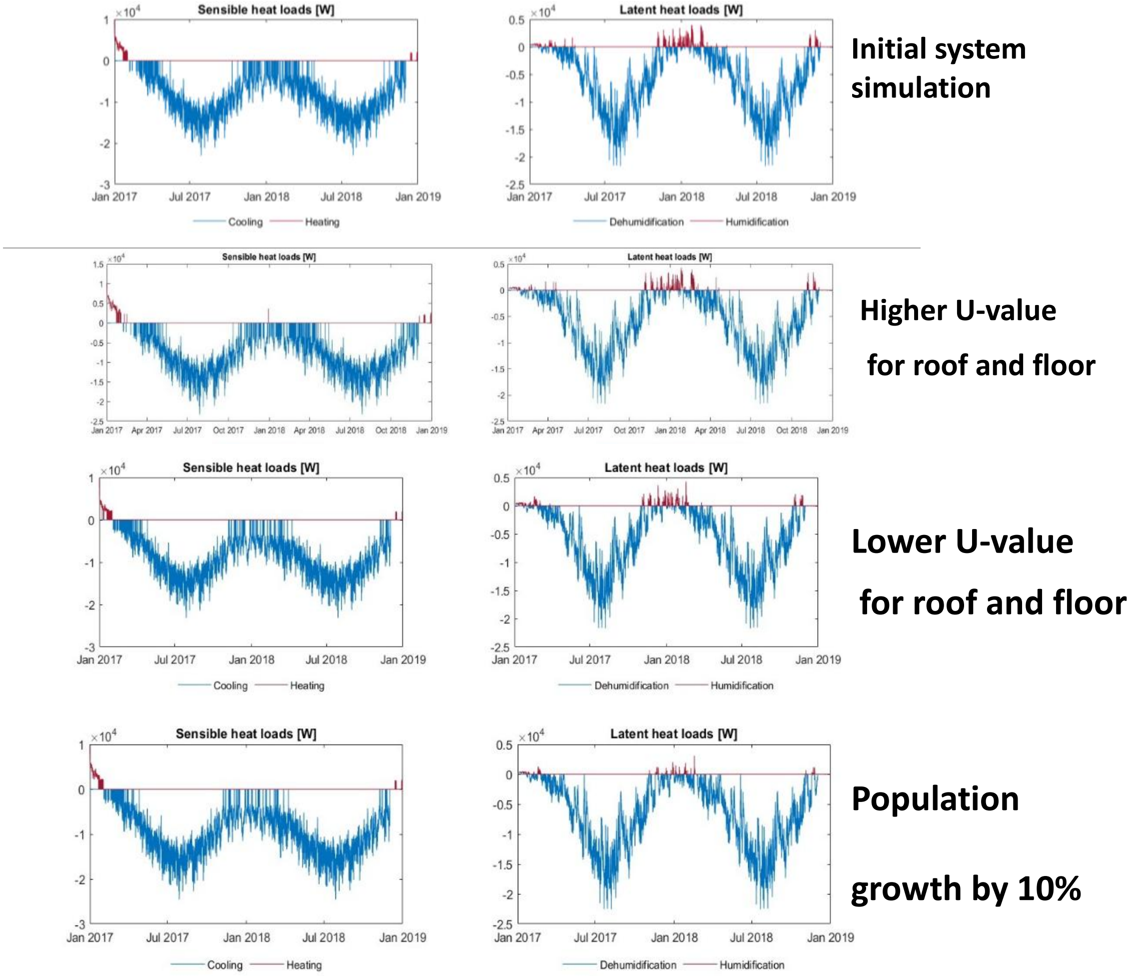


*Figure 34 Trends of sensible heat loads and latent heat loads of monitored values in AUA farm in studied cases*

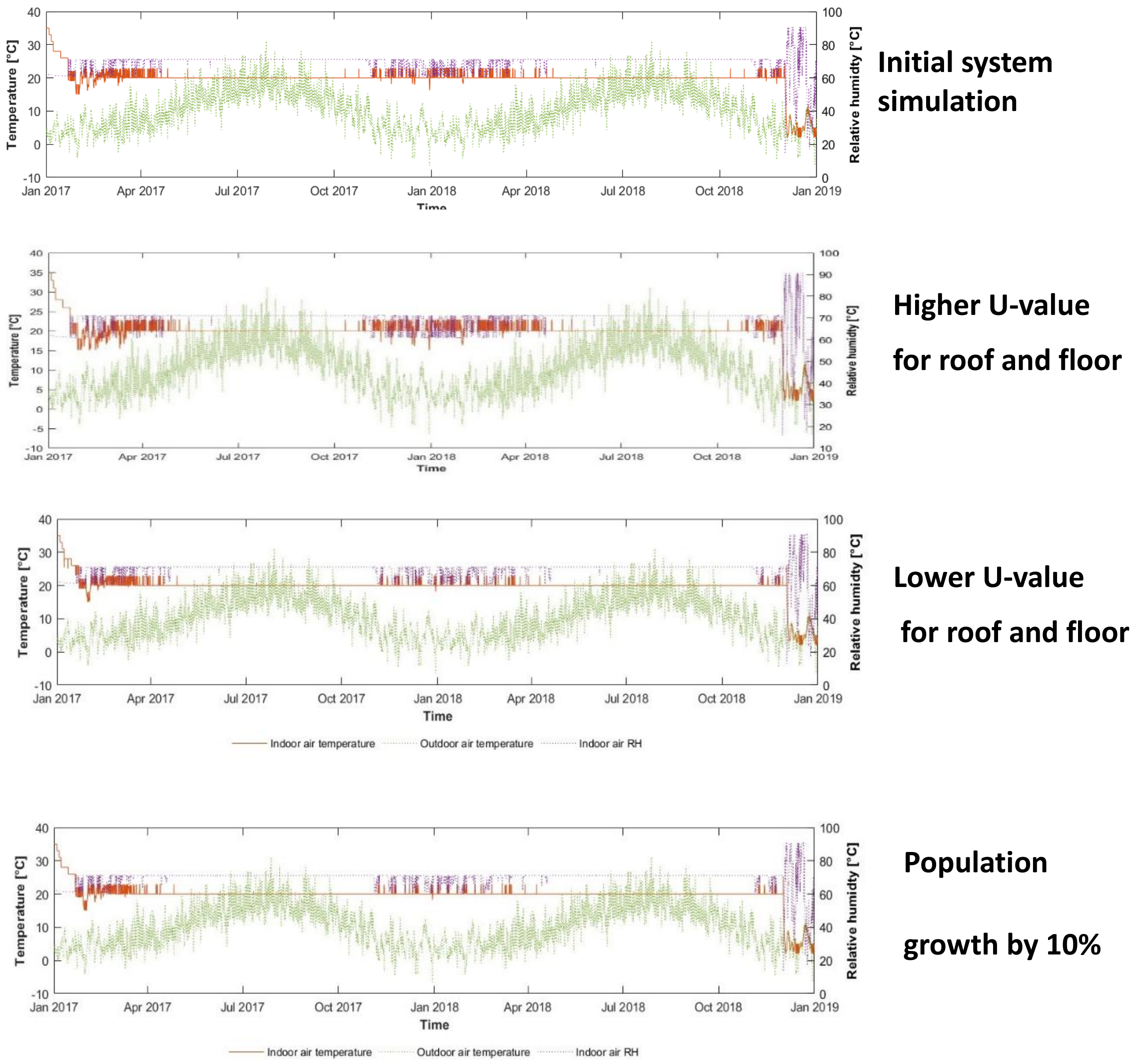


*Figure 35 AUA farm - Indoor air temperature, outdoor air temperature and indoor Relative humidity (°C) at the required temperature set point of 20°C*

## 6.3 Simulated Monthly Energy Consumption (kWh)

Finally, this section closes with the recording of the energy consumption (in kWh) of the cases presented in the section below of this chapter in comparison with the data in comparison with the measured consumption, simulated one and the three different new cases. The consumption was calculated for the month - December as recorded in T5.1.

For the relevant calculation, the average hourly loads were calculated, under seasonal COP 3.65 for the AUA case and 3.88 for the ILVO case respectively, for the same one-month period as in D3.4. As expected, when the thermal efficiency of the building is enhanced, the energy needs that need to be met are drastically reduced.

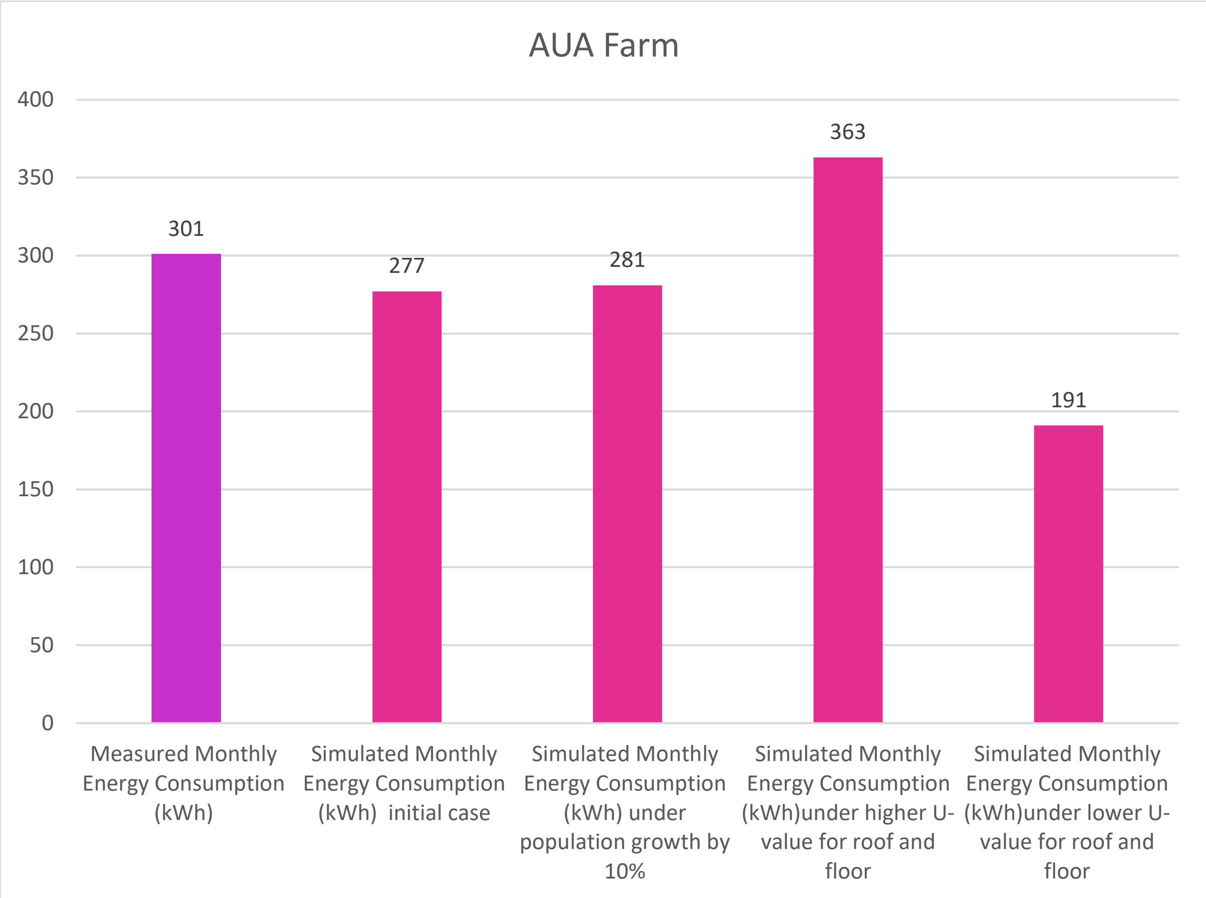


*Figure 37 Measured monthly energy consumption [kWh] of AUA compartment under different case studies.*

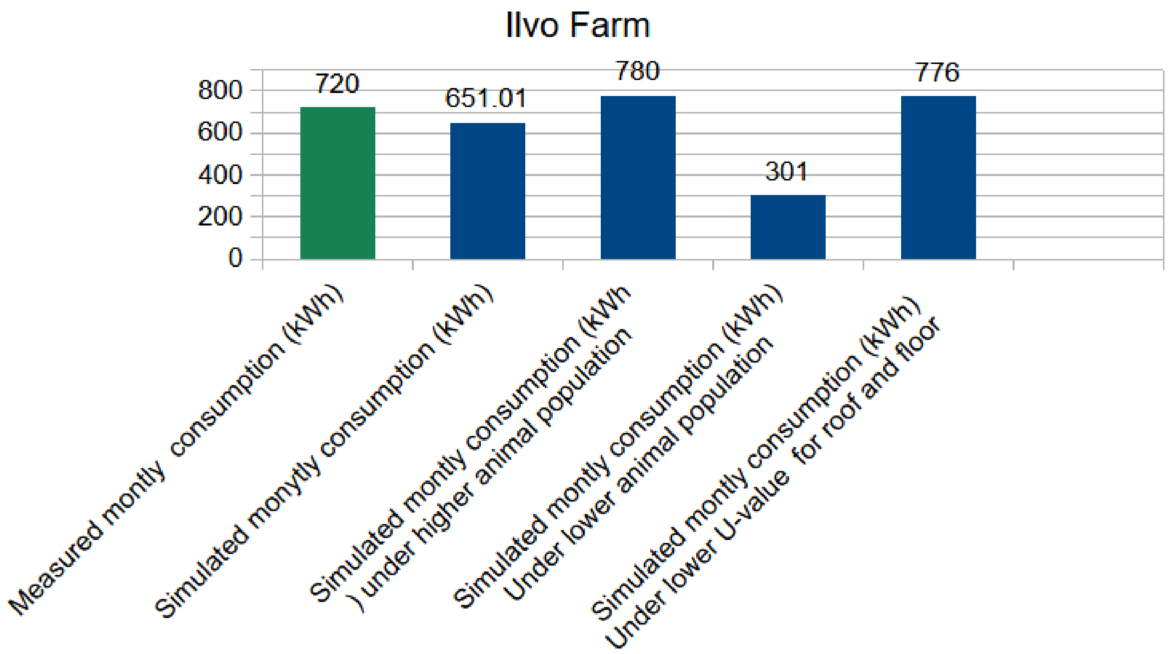


*Figure 38Measured monthly energy consumption [kWh] of Ilvo farm compartment under different case studies.*

It is observed that small variations in the building elements of the farm can bring about notable changes in the energy consumption required to maintain the desired temperature range. Similar conclusions can be drawn if one increases or decreases the live population. Of course, in the case of the AUA poultry farm, we saw that the temperature profile improved with a 10% increase in population and consumption increased slightly. This requires further techno-economical study in order to optimize the financial flows of a sustainable farm of this kind.

# 7 CONCLUSIONS

The current deliverable agrees with the research literature that finds the management, recording and optimization of energy needs on livestock farms a complex issue due to the wide range of different farm cases, particularly when referring to facilities with narrower livestock dynamics, and the lack of up-to-date data (Weiss & Leip, 2012; Mančić et.al., 2016; Paris et.al., 2022).

Regarding the proposal for energy-efficient solutions and/or realistic technical options with a reduced or zero carbon footprint for the new case studies, using the farm-specific toolset developed in T3.4, these could not be implemented due to the extensive changes that would first need to be made to the toolset[16]. Furthermore, it should be noted that no data were available regarding the detailed layout of the 15 new cases or the spatial configurations. Typically, the age of an installation poses multiple challenges for energy evaluation, not only due to poor or absent insulation but also because there is often no recorded data on the topography and layout of the buildings. This issue is less common in industrial-type facilities.

The methodology of the group of tools of T3.4 was used, with appropriate necessary estimations and assumptions where there was not enough data or no data at all, in order to calculate the thermal load of each case.

Several assumptions were made, according to the existing literature, to make an assessment as close as possible to real conditions of thermal capacity of each installation and in the continuation of the peak building heat loss (kW) as a valuable element that can indicate a heat pump size in order to enter a low carbon heat source.

A qualitative element that is of interest to demonstrate in this work has to do with the gathering of the required information, a rather difficult task that proved to be rather time-consuming. Livestock farmers did not respond to our invitation to participate in this survey. This happens for a number of reasons. In several cases, they did not have a material counterpart for their own installation. That indicated the possibility of them being unwilling to make investments in their facilities, especially if the facility is of a small volume.

Conversely, large-scale farm owners appear more willing to invest in decarbonizing energy solutions but are less inclined to provide the requested data. Furthermore, it was noted that no data had been recorded on the farm's building infrastructure or its precise energy consumption.

Furthermore, a parametric analysis of the case-specific model that was constructed was performed, where sample cases were recorded that certify the pivotal role of all the parameters studied and reflected in the constructed model of T3.4. This model can be the potential basis for developing a mass-implemented tool for an in-depth examination of current energy systems in the livestock sector.

[16] Based on the insights gained during the project and the reviewers' feedback at the 2nd Review Meeting, it was decided to focus the efforts of T3.4/D3.4 and the resulting numerical toolset on estimating the required thermal loads of enclosed buildings.

# REFERENCES

Hoffmann, Irene & From, Tatiana & Boerma, David. (2014). Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists.

Moral-Munoz, J.A.; López-Herrera, A.G.; Herrera-Viedma, E.; Cobo, M.J.(2019) Science mapping analysis software tools: A review. In Springer Handbook of Science and Technology Indicators; Glänzel, W., Moed, H.F., Schmoch, U., Thelwall, M., Eds.; Springer Handbook; Springer: Cham, Switzerland; pp. 159–185

Van Eck, N.J.; Waltman, L.; Dekker, R.; van den Berg, J. (2010) A comparison of two techniques for bibliometric mapping: Multidimensional scaling and VOS. *J. Am. Soc. Inf. Sci. Technol. 61*, 2405–2416.

Van Eck, N.; Waltman, L. (2014) Visualizing bibliometric networks. In *Measuring Scholarly Impact: Methods and Practice*; Ding, Y., Rousseau, R., Wolfram, D., Eds.; Springer: Cham, Switzerland, pp. 285–320

Zhang, Y.; Thenkabail, P.S.; Wang, P. (2019) A Bibliometric Profile of the Remote Sensing Open Access Journal Published by MDPI between 2009 and 2018. *Remote Sens.* **p***11*, 91.

Arsenos, G., 2017. Description of ETAK Strategic Actions in Animal Production for the years 2016-2017, General Secretariat of Research and Technology, Animal Production Sector. Thessaloniki. Available online: http://www.gsrt.gr/Financing/Files/ProPeFiles161/%CE%96%CF%89%CE%B9%CE%BA%CE%AE%20%CF%80%CE%B1%CF%81%CE%B1%CE%B3%CF%89%CE%B3%CE%AE.pdf [in Greek]

Magrin, L.; Contiero, B.; Cozzi, G.; Gottardo, F. Data on Gastrointestinal and Claw Disorders as Possible Predictive Factors in Beef Cattle and Veal Calves' Health and Welfare. Data 2022, 7, 43. https:// doi.org/10.3390/data7040043

Vitali M, Nannoni E, Sardi L, Martelli G. Knowledge and Perspectives on the Welfare of Italian Heavy Pigs on Farms. Animals (Basel). 2021 Jun 6;11(6):1690. doi: 10.3390/ani11061690. PMID: 34204037; PMCID: PMC8227195.

Crescio, M. I., Forastiere, F., Maurella, C., Ingravalle, F. & Ru, G. 2010. Heat-related mortality in dairy cattle: A case crossover study. Preventive Veterinary Medicine, 97(3): 191–197

Kelleher, B.P.; Leahy, J.J.; Henihan, A.M.; O'Dwyer, T.F.; Sutton, D.; Leahy, M.J. Advances in poultry litter disposal technology: A review. Bioresour. Technol. 2002, 83, 27–36. [Google Scholar] [CrossRef]

Florin, N.H.; Maddocks, A.R.; Wood, S.; Harris, A.T. High-temperature thermal destruction of poultry derived wastes for energy recovery in Australia. Waste Manag. 2019, 24, 1399–1408

Tańczuk, M.; Junga, R.; Kolasa-Więcek, A.; Niemiec, P. Assessment of the Energy Potential of Chicken Manure in Poland. *Energies* **2019**, *12*, 1244. https://doi.org/10.3390/en12071244

Pedersen, S., et al., A Comparison of Three Balance Methods for Calculating Ventilation Rates in Livestock Buildings, J. agric. Engng Res. (1998) 70, 25—37

Aunedi,M., Olympios,A., Pantaleo,A., Markides, C., Strbac, G., System-driven design and integration of low-carbon domestic heating technologies, Renewable and Sustainable Energy Reviews, Volume 187, 2023, 113695, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2023.113695.

Bandyopadhyay B.and M. Banerjee , Decarbonization of cooling of buildings, Solar Compass, 2, 2022, https://doi.org/10.1016/j.solcom.2022.100025

Stergiou, A., (2016), "Turkey: Correct breeding process", Periodiko Piithros (In Greek)

Richard O'Hegarty, Aidan Reilly, Roger West, Oliver Kinnane,Thermal investigation of thin precast concrete sandwich panels, Journal of Building Engineering, Volume 27,2020, 100937, ISSN 2352-7102,

https://doi.org/10.1016/j.jobe.2019.100937.

Mančić, Marko & Zivkovic, Dragoljub & Djordjević, Milan & Rajic, Milena. (2016). Optimization of a polygeneration system for energy demands of a livestock farm. Thermal Science. 20. 1285-1300. 10.2298/TSCI16S5285M.

F. Weiss, A. Leip / Agriculture, Ecosystems and Environment 149 (2012) 124–134, doi:10.1016/j.agee.2011.12.015

Anna M. Bartkowiak, Energy-saving and low-emission livestock buildings in the concept of a smart farming, JOURNAL OF WATER AND LAND DEVELOPMENT DOI: 10.24425/jwld.2021.139935 2021 , No. 51 (X–XII): 272–278

Paris, Bas & Vandorou, Foteini & Tyris, Dimitrios & Balafoutis, Athanasios & Vaiopoulos, Konstantinos & Kyriakarakos, Georgios & Manolakos, Dimitris & Papadakis, George. (2022). Energy Use in the EU Livestock Sector: A Review Recommending Energy Efficiency Measures and Renewable Energy Sources Adoption. Applied Sciences. 12. 2142. 10.3390/app12042142.

European Commission - "Welfare of Pigs during Production.": Council Directive 2008/120/EC availabe at https://food.ec.europa.eu/animals/animal-welfare/eu-animal-welfare-legislation/animal-welfare-farm/pigs_en#:~:text=Further%20information-,Pig%20welfare,available%20for%20sows%20and%20gilts

Broiler Management Guide" - Cobb-Vantress. Available at : https://www.tt-trade.cz/docs/cobb-broiler-en.pdf

Buoio E, Cialini C, Costa A. Air Quality Assessment in Pig Farming: The Italian Classyfarm. *Animals*. 2023; 13(14):2297. https://doi.org/10.3390/ani13142297

# ANNEX – DATA COLLECTION QUESTIONNAIRE

# Type of farm:

On the following two sections are required topographical characteristics of the farms and of the relevant energy elements, as follows:

## A. Livestock farm's topology

1. What is the farm's volume of livestock (seasonally or average volume)?
2. Where is the farm located?
3. What are the local climatic conditions (min/max temperatures, average moisture)?
4. What are the types of renewable energy sources? [Simple mention, more details to be filled in at the next section]
5. What is the distance from renewable energy sources?
6. What is the distance from residential areas/from goods' distribution centres?
7. What is the wind potential (if measured, else more detailed geographical description)?

## B. Alternative energy sources

Do you utilized renewable energy at your farm? Please choose of the following and explain how?

Is there any of the RES above that you could potentially use?

1. Biomass
2. Wind Energy
3. Solar Energy
4. Geothermal energy
5. Hydroelectric

## C. Final product

Final product output per month (for 12 months) or/and per year.

# Basic building elements

| | | | |
|---|---|---|---|
| **Wall type** | **Type and average thickness of the element:**<br>**Example:** Stones, bricks, timber, blocks, other? | | |
| Type of ceiling | **Type:**<br>**Example:** Timber, galvanized sheets, tiles, fiberglass, other? | | |
| Piping length<br>[A rough estimation - if available] | | | |
| Total surface area<br>(in square meters) | | | |
| Openings (windows, doors, other) in the masonry and/or the roof | **i.e.: Number of openings, location, surface they cover and average thickness of the element** | | |
| Energy consuming devices<br>[Device type requested] | For heating: (example)<br>RES<br>Heat pumps<br>Etc. | For cooling: (example)<br>RES<br>Etc. | Other: |
| Ventilation system<br>[Device type requested] | **Artificial:** | **Natural:** | |
| Dehumidification system<br>[Device type requested] | **Artificial:** | **Natural:** | |
| Lighting<br>[Device type requested] | **Example**: Type of LED, other?<br>Please elaborate | | |

# Farm Energy Log

| | January | February | March | April | May | June | July | August | September | October | November | December | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Electricity** | | | | | | | | | | | | | |
| kWh | | | | | | | | | | | | | |
| price per kWh | | | | | | | | | | | | | |
| Total electric cost | | | | | | | | | | | | | |
| **Diesel** | | | | | | | | | | | | | |
| L/m³ | | | | | | | | | | | | | |
| price per L/m³ | | | | | | | | | | | | | |
| Total diesel cost | | | | | | | | | | | | | |
| **Gasoline** | | | | | | | | | | | | | |
| L/m³ | | | | | | | | | | | | | |
| price per L/m³ | | | | | | | | | | | | | |
| Total gasoline cost | | | | | | | | | | | | | |
| **LPG** | | | | | | | | | | | | | |
| Kg | | | | | | | | | | | | | |
| price per Kg | | | | | | | | | | | | | |
| Total LPG cost | | | | | | | | | | | | | |
| **Natural gas** | | | | | | | | | | | | | |
| m³ | | | | | | | | | | | | | |
| price per m³ | | | | | | | | | | | | | |
| Total natural gas cost | | | | | | | | | | | | | |
| **TOTAL ENERGY COST** | | | | | | | | | | | | | |

**FARM: DIRECT ENERGY USAGE**
Enter your unit usage.
This can be found on your monthly bills.
Also enter the total cost (ie. total electric cost). This is the amount that you pay from your monthly bill.
The worksheet will calculate the per unit cost for you.
Graphs will automatically be generated from the data entered.