PAN POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2021.139935
2021, No. 51 (X–XII): 272–278

Energy-saving and low-emission livestock buildings in the concept of a smart farming

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RECEIVED 05.11.2021 REVIEWED 21.11.2021 ACCEPTED 10.12.2021

Abstract: Smart farming is about managing a farm using modern information and communication techniques in order to increase the efficiency and quality of plant and animal production and to optimise human labour inputs. It is an inseparable part of a sustainable agricultural economy, where energy-saving and low-emission solutions are of particular importance, e.g. in livestock construction. Animal buildings are one of the main building elements of a farm. The paper presents the use of modern solutions that may result in lower energy consumption, and thus lower operating costs of the building. They also reduce the consumption of natural resources and the emission of pollutants, and ensure animal welfare and safety of the operators' work. Rational use of energy depends, among others, on from the used insulation materials for the construction of livestock buildings, technical equipment, i.e. lighting, heating, ventilation, as well as zootechnical devices. The profitability of livestock production can also be supported by the use of solar, wind, water and biomass energy. Photovoltaic cells, solar collectors, wind turbines, heat pumps and agricultural biogas plants are used for this purpose.

Keywords: energy-saving and low-emission livestock building, smart agriculture, sustainable development

INTRODUCTION

Agriculture, like other sectors of the economy, is subject to the principles of sustainable development [Adamowicz 2005; Bartkowiak, Bartkowiak 2012; 2017; Baum 2008; EC 2010; Kiełbasa *et al.* 2018]. In line with the Food and Agriculture Organization of the United Nations Development Program, the primary task of sustainable agriculture is to nurture healthy ecosystems and support the sustainable management of land, water and natural resources, while ensuring global food security. In addition, it enables it to meet the needs of present and future generations for its products and services, while ensuring profitability, environmental health, and social and economic equality [FAO 2015].

Polish agriculture, which is an inseparable part of the European economy, is subject to the regulations of the Common Agricultural Policy (CAP), the main goal of which is to ensure sustainable development in the agricultural sector, including by producing safe and high-quality food, protecting the natural environment, animal welfare, protecting public health and creating local jobs [Adamowicz 2005; Bartkowiak, Bartkowiak 2012; 2017; Baum 2008; EC 2010]. The achievement of the above goal can be achieved thanks to changes in technology and modernisation of technical equipment, improving the efficiency and safety of the farmer's work, improving the living conditions of animals and reducing the emission of pollutants from agricultural activities [Bartkowiak, Bartkowiak 2017; Romaniuk 2010; Rzeźnik (ed.) 2017].

Sustainable development of agriculture consists in the management and maintenance of the natural resource base, as well as the directions of technological and institutional changes, so as to ensure the implementation and constant satisfaction of human needs, present and future generations [FAO 1989].

In the scope of this concept, a special role is played by the technical and technological aspect, which affects the conditions and effects of farming, and thus stimulates changes in agriculture through the appropriate adaptation of mechanisation and automation as well as organisation and management to agricultural production [Bundschuh, Chen (ed.) 2014; Jongebreur, Speelman 1997].

In the National Low-Emission Economy Development Program [MG 2015] one of the priorities of sustainable agricultural production is the transformation and modernisation

of technical, technological and organisational farms, which is to contribute to (Priority C.5. Sustainable development of production in agriculture):
– better equipment of livestock buildings with devices and machines,
– use in the production process of machines and devices of the highest energy class,
– increasing the possibilities for farmers to use advisory services and implementing the recommendations indicated by advisers in the field of improving energy efficiency,
– promoting ecological agricultural production.

The implementation of the idea of smart agriculture may also contribute to the implementation of the above priorities. Smart agriculture is a new concept defined as farm management using modern information and communication techniques in order to increase the efficiency and quality of plant and livestock production and to optimise human labour inputs (Fig. 1) [Berckmans 2017; Dawkins 2021; Goyal 2019; IoT For All 2020]. The tools for precise management in farms are mainly [Arifjanov *et.al.* 2021; IoT For All 2020; Melalih, Mazour 2021]:
– sensors used in soils, in livestock buildings to regulate lighting, air temperature, humidity, monitoring animal welfare;
– drones and cameras to monitor the farm;
– software adapted to the specific type of farm;
– cellular communication, GPS or satellite location;
– modern machines and devices (automation and robotisation);
– new, energy-saving technologies (e.g. renewable energy sources).

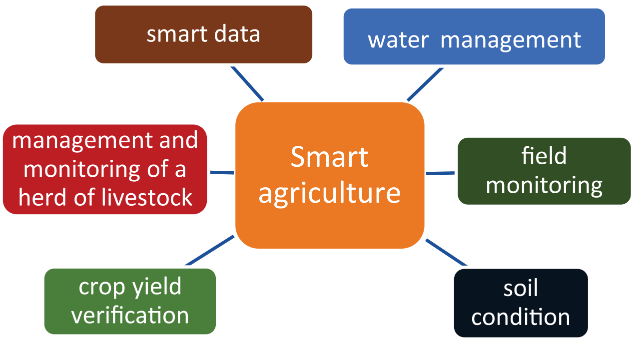

Fig. 1. Smart agriculture determinants; source: own study based on Goyal [2019]

Thanks to these tools, farmers can monitor, based on observation and diagnosis, conditions on the farm, both in the field and in the livestock building, and make strategic decisions.

Two areas can be distinguished in farms [IoT For All 2020]:
– precision farming related to crop production, where intelligent tools are used to e.g. map the spatial variability of as many variables as can be measured (e.g. yields, terrain features/ topography, soil organic matter, moisture level, nitrogen level, etc.);
– precise livestock breeding, involving the use of smart farming techniques to ensure animal welfare, including better monitoring of individual animal needs and appropriate adjustment of feed rations, animal health monitoring and the use of energy-efficient and low-emission techniques and technologies in livestock buildings. It allows the farmer to obtain economic benefits, thanks to lower energy consumption and lower operating costs of the building, and also contributes to the protection of the natural environment by reducing the consumption of natural resources and emissions of pollutants.

Due to the enormous opportunities offered by intelligent agriculture, based on information and communication techniques, it is called the green revolution, because it is pro-environmental, enables the production of high-quality and safe food, meets animal welfare requirements, is economically beneficial (the use of energy-saving techniques and technologies) and reduces the amount of human labour [IoT For All 2020].

REQUIREMENTS FOR ENERGY-SAVING AND LOW-EMISSION BUILDINGS

Livestock buildings are the basic element of farm buildings, focused on livestock production. There are rooms for animals, auxiliary and service rooms as well as machines and devices for animal husbandry and breeding. Each livestock building must: meet the material, construction and spatial requirements, ensure high comfort for animals (welfare), use functional, energy-saving and low-emission solutions related to feeding, watering animals, removal of animal excrements, ventilation and heating systems and an emergency system, ensure safety service work and be economically viable [Kołacz, Dobrzański (ed.) 2006; Romaniuk 2010].

One of the conditions for rational livestock production is the desire to minimise energy consumption, inter alia, through various solutions used in livestock construction while maintaining high efficiency of internal devices and installations. Energy consumption may refer to both the total consumption for all needs related to the day-to-day operation of the facility, and to the individual components. It depends on the materials used for the construction of livestock buildings, equipment, i.e. lighting, heating, ventilation and zootechnical devices (milking parlors, milk coolers, water heaters, devices for the preparation and distribution of feed and the disposal of animal excrements) [Kołacz, Dobrzański (ed.) 2006; Romaniuk 2007].

In energy-saving construction, renewable sources of electricity and heat are increasingly used. Solar collectors using photothermal conversion are used to heat domestic hot water, and heat pumps or biomass boilers are used for heating. The sources of heat and electricity are also agricultural biogas plants, a photovoltaic installation or a small wind turbine. Improving the efficiency of energy use is related to Good Practices, as well as the selection and use of energy-saving animal husbandry devices and the proper design of buildings for animals. Overall operational measures may be reduced if the best available housing capacity is used and the animal density is optimised [EC 2017].

An important way to reduce energy consumption is to implement an action plan. With energy plans, you can focus on information about the options available and how to save energy, and thus reduce operating costs. The collected information on energy consumption must be related to the production processes and stages, the type of livestock building and external factors such as weather. In order to monitor changes in energy consumption, it is necessary to read the meters on a regular basis. In addition, maintenance and repairs of the installation housing, devices or the building itself should be carried out, as well as systematic cleaning of livestock equipment, because both dust and emerging corrosion are the main problems that adversely affect the devices (e.g. heaters, fans or controllers) and their correct and long-lasting operation [EC 2017].

ENERGY-SAVING AND LOW-EMISSION SOLUTIONS IN INVENTORY BUILDINGS

In animal husbandry, it is extremely important to ensure a proper microclimate in livestock housing. Proper climatic conditions inside the building are ensured by the insulation of the ceiling, roof, walls and floor [Kołacz, Dobrzański (ed.) 2006]. Heat losses in the walls of pig houses with 2 cm insulation can be 20% higher than in the same building with 8 cm insulation. This is the equivalent of 10,500 kWh (or EUR735·y^{-1}) in potential annual savings [EC 2017].

The materials used for insulation are selected depending on their thermal conductivity coefficient. The smaller it is, the better the material has insulating properties. In addition, the insulation function is performed by materials used in accordance with the place of use, i.e. inside or outside the building. Insulation should be characterised by many properties, including resistance to: putrefying bacteria, mold and fungi, the effects of birds, rodents and insects, high temperature, corrosion in gas and liquid environment, disinfection and regular washing and cleaning under pressure. In addition, they should not absorb water and steam, and release substances harmful to the health of animals and the handler [EC 2017; Godlewska 2011].

Lighting plays an important role in animal enclosures. It allows the animal to orientate itself in the room, facilitates the search for feed and its better use, contact with other animals, supports its vital and productive activity [Kołacz, Dobrzański (ed.) 2006].

The livestock building uses natural (day) and artificial (electric) lighting. Its purpose is to ensure high animal welfare and facilitate the work of the operator. The artificial lighting system should be designed in such a way as to meet the requirements of animals, provide good working conditions for people and be energy-efficient. Depending on the species and age of the animals, a minimum light intensity should be provided [Kołacz, Dobrzański (ed.) 2006].

Low energy lighting requires [Godlewska 2011; Kołacz, Dobrzański (ed.) 2006]:
- replacing conventional tungsten light bulbs with fluorescent, sodium or LED lamps;
- using dimmers to adjust the lighting;
- lighting control using sensors or switches;
- use of lighting schemes (energy savings of 30–75%);
- introducing photoelectric cells to turn on the light (mainly in corridors).

Currently, LED lighting is increasingly used in livestock rooms, which achieves a luminous efficiency unattainable for other products – even 100 lm·W^{-1} [Krulen undated]. There is also little heat emission, thanks to which the LEDs have a lifetime of 50,000 h. Thanks to this, you can not only save energy, but also take care of the natural environment:
- reduces CO_2 emissions by 80% compared to a conventional light bulb,
- no harmful substances, e.g. mercury (LED is 100% biodegradable),
- high colour quality with minimal UV radiation,
- several times lower energy consumption,
- many times longer service life,
- unlike fluorescent lamps, LED reaches full brightness immediately after being turned on, and frequent switching on and off will not shorten service life.

In livestock housing, lower energy consumption can also be achieved by installing a programmable timer. It enables programming during the day of light, automatic switching on and off of lighting at a given time and a smooth change of light intensity (rate of change), i.e. simulating dawn and dusk and selection of the light intensity level. Moreover, the use of a timer significantly influences the vital functions and productive performance of animals. [Godlewska 2011].

Ventilation is an extremely important factor affecting animal welfare and the technical condition of the building, which ensures the supply of fresh air and removes unwanted gases, maintains the appropriate temperature and air humidity [EC 2017; Kołacz, Dobrzański (ed.) 2006]. According to BAT [EC 2017], the speed of ventilation has a significant impact on energy saving. As a result of excessive air exchange, heat losses in pig buildings can be as high as 75%. Natural ventilation is the most economical form. However, this is not always possible for all species and with the maximum stocking density indoors. The ventilation system should be designed to remove additional heat in the warm summer months at the highest stocking density and also be able to provide a minimum degree of ventilation in the cooler winter months at the lowest stocking density. Energy-efficient fans are required to be installed in energy-efficient livestock buildings [Godlewska 2011; Polnet undated; WentylatorySklep.pl undated]. Fans with a low rated speed (low speed units) consume less energy than fans with a high speed (high speed units). Fans with a low rated speed (low speed units) consume less energy than fans with a high speed (high speed units). However, low speed fans can only be used if the ventilation system has a low air flow resistance (<60 Pa). Fans designed on the basis of electronic commutation technology have a significantly lower power requirement, especially in the range of regulated speeds, compared to fans regulated by transformer or electronically regulated. When using centralised ventilation, reductions in energy consumption are generally between 20 and 30% [EC 2017].

In order to secure in the event of a failure of the electronically controlled ventilation and possible power outages, the installation should be supplemented with an emergency module, which in the event of unexpected breaks in the ventilation operation will inform the operator via a message to the mobile phone. This solution will protect against sudden accidents and possible losses [WentylatorySklep.pl undated].

In livestock buildings, the heat of the animals is in many cases sufficient to maintain the correct temperature in the building. A large amount of bedding also helps the animals to maintain their thermal comfort [Kołacz, Dobrzański (ed.) 2006]. For example, in an integrated pig farm, heating accounts for 46% of the total energy consumption and about 80% of the total energy consumption in farrowing and piglet rearing houses. When optimising the heating and ventilation balance, it should be adapted to the needs of the animals, which can reduce energy consumption by up to 50% [EC 2017] Some options for reducing energy consumption for heating are: reducing ventilation, taking into account the minimum levels required for performance and animal welfare, lowering the temperature, where animal welfare and production permits, insulating the building, especially over heating pipes, optimising positioning and regulation heating equipment, taking into account heat recovery, considering the use of high-efficiency boilers, regular checking of temperature sensors calibration.

In the case of young animals, the solution is to use infrared heaters, which stimulate circulation, metabolism and the immune system. This translates into their better condition and faster growth. Energy should be used efficiently, for example by arranging lying areas surrounded by full wooden partitions and with a roof. This is the so-called ecological niche that works like an incubator. This makes it possible to create two thermal zones in the pen – warmer for lying down and colder for physical activity and eating [EC 2017; Kołacz, Dobrzański (ed.) 2006].

The essence of the effective use of specialised technical equipment for milk production are: milking parlour, washing room and milk cooler with heat recovery. This selection should be carried out mainly in terms of precise adjustment of operating indicators of devices to the current and future volume of milk production on the farm [Krysiak 2014; Łaska, Szulc 2012; Szulc 2007; 2012].

Heat recovery allows for quick and inexpensive cooling of milk and, as a result, heating of a certain amount of utility water for sanitary purposes to a temperature of up to 70°C, improving the efficiency of milk coolers. The hot water produced by the system can be used to heat the water boiler for washing the milking system or the cooler. For every 1 litre of cooled milk, the heat recovery system heats 1 dm^3 of water by 10°C. The water temperature depends on the power consumption of the cooling system and the cooling time. Heat recovery is one way to cut costs [Krysiak 2014; Łaska, Szulc 2012; Szulc 2007; 2012].

Milk coolers equipped with energy-saving cooling units allow you to save up to 30% of energy. It is an innovative system that recovers the heat generated by the cooling unit to use it to heat the domestic hot water tank to 55°C and more, regardless of the ambient temperature. Unlike traditional recovery systems, it can recover all the heat from the cooling and condensing phases. Thanks to this two-phase method, it is enough to cool one litre of milk from 35 to 3°C to heat one litre of water from 12 to 55°C. We can get many benefits from refrigeration equipment without compromising the protection of the environment. With low energy consumption, it ensures heat recovery of up to 70% [Krysiak 2014; Łaska, Szulc 2012; Szulc 2007; 2012].

On farms, you can also use other solutions that reduce gas pollution in livestock buildings, for example [Big Dutchman 2020; MRiRW 2019; Walczak 2017; Walczak, Krawczyk (ed.) 2017]:

1) biofilters – devices for reducing air pollution with the use of an organic filtering medium. Mixtures of peat, straw, sawdust, and clayey earth are used as the filtration medium. It is placed on a special structure with a large surface, and there is an empty space under the filter material; air pollutants are removed or neutralised in two ways: by settling and accumulating them, or during the process of digestion by microorganisms; the emission reduction can be on the level of: CH_4 20–60%, NH_3 and H_2S 50–90%;
2) air cleaning system – it is a decentralised exhaust air cleaning system which, combined with very low energy consumption and a small amount of waste water, minimises the emission of gases from the building and removes dust; the system contains multiple nozzles that spray the water in the channel and thus bind ammonia and dust; the pH of the water is monitored on an ongoing basis; it can be reused. It allows for cleaning the reduction of NH_3 in over 90% as well as dust (up to 94%) and unpleasant odours;
3) slurry channels – replacement of U-shaped channels by V-shaped channels; reduces the evaporation surface and reduces the emission of gaseous pollutants; it reduces the emission of ammonia to 30%, the reduction of CH_4 and N_2O emission by about 20%;
4) slotted floor manure robot – cleans crevice floors with scrapers that push animal excrement between the slots of the concrete floor of the slurry corridor into underground storage pits; it is a fully automatic device that enables cleaning of the entire building at programmable intervals; the robot is powered by electricity from built-in batteries. In addition, cleaning the floors with less moisture, which has a positive effect on well-being; the emission reduction may amount to CH_4 12% and N_2O approx. 15%.

The use of renewable energy sources in livestock construction is a significant solution in modern agriculture. Virtually all renewable energy sources can be used: sun, wind, water, biomass and earth [Godlewska 2011; Grzybek, Pawlak 2015; Oniszk-Popławska *et al.* 2011; Szlachta 1999].

Solar collectors, photovoltaic panels, heat pumps and agricultural biogas plants play a special role in the process of processing natural energy sources [Godlewska 2011; Grzybek, Pawlak 2015; Oniszk-Popławska *et al.* 2011; Szlachta 1999]. The use of the Sun's energy potential offers many opportunities for technological development and activities for the conscious regulation and diversification of energy sources. A special type of heat exchanger is a solar collector. It converts the energy of solar radiation into heat. On the other hand, photovoltaic cells are used to convert solar radiation into electricity. A heat pump is a device that uses the heat of the surrounding environment (air, soil, surface and underground waters, heat generated in production processes) for heating purposes. In energy-saving construction, the obtained heat can be used for cleaning installations, rooms, local heating of animals, heating drinkers, process water, sanitary water in technical and social rooms, and space heating. On the other hand, a biogas plant is an installation in which the organic waste fermentation process takes place. The resulting biogas in livestock construction can be used as a source of electricity and heat [Grzybek, Pawlak 2015].

PRECISE BREEDING OF LIVESTOCK

The concept of smart farming makes it possible to run a farm more efficiently and productively as it involves the use of technology to monitor and manage livestock farming and breeding [Berckmans 2017; Dawkins 2021; O'Grady, O'Hare 2017; Deloitte 2017] Monitoring of animals and controlling the environment can be carried out continuously, in real time, which is important in preventing adverse events, e.g. diseases in animals, or deterioration of animal welfare as a result of changes in microclimatic parameters in a livestock building.

Dawkins [2021] based on the research of various authors, he gave examples of the possibility of monitoring animals with injuries. Detection of e.g. lameness in dairy cows can be done through visual images, accelerometer data from devices mounted on the cows' legs, pressure-sensitive pads that record how the cows distribute their weight, and even from the sound of their step or changes in behaviour, i.e. by lying the animals longer and shorter chewing time. Digital imaging technology can also be used to detect tail biting in pigs by changing the position of the tail, or lameness in broilers due to abnormal body oscillations, frequency and stride length. In large animals (cows, pigs), markers, trackers or measuring devices can be placed on or inside the body of each animal for individual monitoring, or visually check individual animals with cameras.

The decision support tools may be different models, depending on the agricultural activity, carried out independently or combined with other models. O'Grady and O'Hare [2017] believe that models such as GPFARM, APSIM, GRAZPLAN are usually general in nature and their adoption by individual farmers is minimal. Smart technologies, on the other hand, make it possible to use farm-specific models. Yadavalli *et al.* [2020] emphasise that animal welfare is closely related to environmental parameters in livestock housing. Monitoring and control of environmental parameters in livestock buildings can be performed on the basis of a wireless network of sensors. It is considered to be a method by which labour costs and energy consumption are reduced. Using the WLS algorithm, the following parameters are controlled in real time: temperature, humidity, light intensity, carbon dioxide concentration, ammonia concentration and hydrogen sulphide concentration. Additionally, the system can track the location of the animals in the livestock building using several tracking nodes around the animal's neck. This method also provides for the possibility of using an ALEXA-based voice assistant, which can help us control and monitor the parameters of the livestock.

In the process of herd monitoring, the Internet (IoT) is very important, i.e. a system of interconnected computer devices, mechanical and digital machines, various objects and animals, which are provided with unique identifiers and the ability to transfer data over the network without the need for human-to-human or human interaction computer. The connection of internet networks with electronics, software, sensors, monitors, transmitters, receivers enables the collection and storage of data. On the basis of the developed website, it is therefore possible to monitor the condition of animals and the environment of animals [Shah et al. 2019].

SUMMARY

The role of energy-saving and low-emission livestock buildings in agricultural production is growing. It meets all aspects of sustainable development in terms of social, ecological and economic terms and contributes to increasing the efficiency of agricultural production thanks to the use of modern information and communication techniques. Energy consumption in construction for livestock production can be reduced by using rational solutions. In this regard, it is necessary, first of all, to protect the building against heat losses and other factors deteriorating the technical condition of the building, to optimise the air flow thanks to appropriate ventilation devices, to use energy-saving lighting and heating devices in accordance with zoohygienic requirements and to use heat recovery devices. The above solutions can be supported by devices using natural energy sources, thanks to which operating costs can be reduced, as well as having a great pro-environmental importance.

In conclusion, based on the analysis carried out in this paper, it can be said that intelligent animal husbandry has very many benefits for both farmers (socially and economically), animal welfare and the environment (Tab. 1). The use of tools such as sensors, cameras, software, GPS, cell phones, computers for data analysis and others supports the process of animal production management increasing the efficiency and quality of production and optimises human labour input.

Table 1. Benefits of implementing smart animal farming

Aspect	Benefit
Animal welfare	- improving the living conditions of animals - monitoring the needs of individual animals - adapting feed rations as necessary - monitoring animal health - monitoring animal location
Environmental	- reducing pollution emissions by using low-emission techniques and technologies in livestock buildings - reduce consumption of natural resources - use of renewable energy sources
Social	- improve farmer's productivity and safety - reduction of human labour input
Economic	- obtaining lower costs of using livestock building through application of energy efficient techniques and technologies - reducing costs of animal treatment - increased income resulting from better animal productivity
Technical-technological	- adapting mechanisation and automation, organisation and management to agricultural production - modernisation of technical equipment - application of information and communication techniques

Source: own study.

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