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ANIMAL ACTIVITY TO IMPROVE THE WELFARE AND ENERGY AND PRODUCTIVE EFFICIENCIES IN INTENSIVE PRODUCTION BUILDINGS OF PIGLETS

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Animal activity to improve the welfare and energy and productive efficiencies in intensive production buildings of piglets

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D. Roberto Besteiro Doval

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Atentamente
O Autor

Abstract

Abstract

Livestock sector is currently facing two great challenges: achieve a more environmentally friendly production and to ensure animal welfare in the building, taking into account the productivity. One of the most efficient ways of approaching such claims is through climate control system and environmental control. In this sense, and thanks to the development of *Big Data* and concepts such as *Smart Farming,* new mechanisms are emerging to be employed as an indispensable tool to achieve the objectives referred.

These new tools include new control algorithms of climate control system, which allows the inclusion of different variables. Among the huge variety of variables that could be employed inside a livestock farm, activity or animal behaviour is one of the more promising. The activity is able to integrate into a single variable, elements related to animal welfare as well as the air quality of the room.

In this thesis, submitted under the modality of compendium of publications, it is pursued to improve animal welfare and energy and production efficiency in weaned piglet farms. For this goal, the possibilities to integrate the animal activity in the incipient systems of predictive climate control are evaluated. During two breeding cycles, different environmental variables and variables related to animal were recorded in a room with weaned piglets from 6 to 20 kg of live weight. The 10-min averages of the measured values of 30 variables, at 1-s intervals, were stored in a data logger. Among these variables, highlight the temperature, humidity, carbon dioxide concentration (CO_2), air velocity or animal activity.

In order to measure animal activity, a robust reliable and low cost measurement method was established. This method use passive infrared detectors. The validity of these measurements was checked by comparing them with a direct observation of the animals, by a qualified person. The registered values by both methods were on agreement, with values of Concordance Correlation Coefficient of 0.86 and Spearman Coefficient Correlation of 0.90. However, the accuracy was not constant; it was higher at the beginning of the cycle, when the animals were smaller. Afterwards, a spectral analysis of the complete series of activity was performed using the Fast Fourier Transform (FFT) and Continuous Wavelet

Transform. This process confirmed the influence of the types of environmental and management factors on animal activity, such as light/dark periods or the distribution of food. In addition, it was established a range of sinusoidal equations that define the activity of the piglets.

In general, during the cycle the animals showed two peaks of activity at 10:00 and 18:00 h, with a night rest period between 22:00 and 07:00 h. Nevertheless, during the first half of the cycle, a simpler behaviour pattern was detected, with a single peak of activity, mainly due to the less competition for space in the pen. Finally, these activity patterns were used in a hybrid model which combined The Discrete Wavelet Transform with Artificial Neural Network, so-called Wavelet-Neural Network. The results from this model, used for CO_2 prediction in livestock buildings, predict the following value of concentration with a root mean square error of 154 ppm. In addition, a delay of almost one hour between the moment of activity and its response in the gas concentration was detected. Despite everything, the best predictive results were achieved by a model with an autoregressive character that used the past values of the own CO_2 series, which is indicative of the high inertia of this variable in the room.

In conclusion, it was confirmed that the activity measurement system through passive infrared sensors is a reliable and economical method that allows registering animal behaviour patterns. These patterns, or own activity values, could be used in predictive models of indoor climate in order to achieve a more efficient control of climate control systems.

Resumo

Na actualidade o sector gandeiro enfróntase a dous grandes retos: alcanzar unha produción máis respectuosa co medio ambiente e menos contaminante e asegurar unhas condicións de benestar animal no aloxamento, sen esquecerse da súa finalidade produtiva e económica. Unha das maneiras máis eficaces de abordar esta dobre pretensión nas explotacións intensivas é a través dos sistemas de climatización e control ambiental. Neste sentido, e grazas ao desenvolvemento do *Big Data* e de conceptos como o *Smart Farming*, xorden novos mecanismos que poden ser empregados como unha ferramenta indispensable para lograr os mencionados obxectivos. Entre estas novas ferramentas inclúense novos algoritmos de control dos sistemas de climatización que permiten a inclusión de distintas variables. E precisamente, de entre a enorme variedade de variables que se poderían empregar dentro dunha explotación gandeira, a actividade ou o comportamento dos animais é unha das máis prometedoras. Isto é así porque permite integrar nunha única variable aspectos relativos ao benestar animal e á calidade do aire do aloxamento.

Nesta tese, presentada baixo a modalidade de compendio de publicacións, perséguese conseguir unha mellora no benestar animal e as eficiencias enerxética e produtiva das explotacións de gando porcino en fase de transición. Para iso avalíanse as posibilidades de integración da variable actividade animal nos incipientes sistemas de control ambiental predictivos.

No desenvolvemento deste traballo, rexistráronse distintas variables ambientais e de carácter animal nunha sala dunha explotación de leitóns desmamados de 6 a 20 kg durante dous ciclos completos de cría. Almacenáronse nun colector os valores dez-minutais de ata 30 variables, entre as que destacan a temperatura, humidade, concentración de CO_2, velocidade do aire ou a actividade animal.

É precisamente a actividade animal, variable de estudo nesta tese, para a cal se estableceu un método de medición robusto, fiable e de baixo custo a través de sensores de infravermello pasivo. Comprobouse a validez destas medicións mediante a súa comparación cunha observación directa dos animais por unha persoa cualificada. Púidose confirmar a concordancia entre os valores rexistrados

por ambos os métodos, con valores do Coeficiente de Correlación de Concordancia de 0,86 e correlación de Spearman de 0,90. Con todo, a precisión non foi constante ao longo de ciclo, senón que esta foi maior ao principio do mesmo, cando os animais eran máis pequenos e lixeiros. Posteriormente procedeuse a realizar unha análise espectral da serie completa de actividade mediante a Transformada Rápida de Fourier e a Transformada Wavelet Continua. Deste proceso confirmouse a influencia dos distintos factores ambientais e de manexo sobre a actividade animal, como os períodos de luz/escuridade ou o horario de repartición de alimento. Ademais, establecéronse unha serie de ecuacións sinusoidales que definen a actividade dos leitóns. En xeral, durante o ciclo os animais mostraron dous picos de actividade ás 10:00 e ás 18:00 h, cun período de repouso nocturno entre as 22:00 e as 07:00 h. Con todo durante a primeira metade do ciclo detectouse un patrón de comportamento máis simple, cun único pico de actividade, debido principalmente á menor competencia polo espazo no curral. Finalmente, estes patróns de actividade foron empregados nun modelo híbrido que combinou a Transformada Wavelet Discreta con Redes Neuronais Artificiais, denominado modelo Wavelet- Neural Network. Os resultados deste modelo, empregado para a predición da concentración de CO_2 no aloxamento, demostran que a inclusión da actividade xunto coa temperatura da sala e a temperatura exterior predín o seguinte valor de concentración cunha raíz do erro cuadrático medio de 154 ppm. Ademais detectouse un retardo de case unha hora entre o momento de actividade e a súa resposta na concentración do gas. Os mellores resultados predictivos alcanzáronse a través dun modelo autorregresivo, que emprega os valores pasados da serie de CO_2, indicativo da elevada inercia desta variable.

A modo de conclusión confirmouse que o sistema de medición da actividade a través de sensores de infravermello pasivo é un método fiable e económico que permite rexistrar os patróns de comportamento dos animais. Estes patróns, ou os propios valores de actividade, poden ser empregados en modelos predictivos do clima en aras a lograr un control máis eficiente dos sistemas de climatización.

Resumen

En la actualidad el sector ganadero se enfrenta a dos grandes retos: alcanzar una producción más respetuosa con el medio ambiente y menos contaminante y asegurar unas condiciones de bienestar animal en el alojamiento, sin olvidarse de su finalidad productiva y económica. Una de las maneras más eficaces de abordar esta doble pretensión en las explotaciones intensivas es a través de los sistemas de climatización y control ambiental. En este sentido, y gracias al desarrollo del *Big Data* y de conceptos como el *Smart Farming*, surgen nuevos mecanismos que pueden ser empleados como una herramienta indispensable para lograr los mencionados objetivos. Entre estas nuevas herramientas se incluyen nuevos algoritmos de control de los sistemas de climatización que permiten la inclusión de distintas variables. Y precisamente, de entre la enorme variedad de variables que se podrían emplear dentro de una explotación ganadera, la actividad o el comportamiento de los animales es una de las más prometedoras. Esto es así porque permite integrar en una única variable aspectos relativos al bienestar animal y a la calidad del aire del alojamiento.

En esta tesis, presentada bajo la modalidad de compendio de publicaciones, se persigue conseguir una mejora en el bienestar animal y la eficiencia energética y productiva de las explotaciones de ganado porcino en fase de transición. Para ello se evalúan las posibilidades de integración de la variable actividad animal en los incipientes sistemas de control ambiental predictivos.

En el desarrollo de este trabajo, y para alcanzar los objetivos deseados, se registraron distintas variables ambientales y de carácter animal en una sala de una explotación de lechones destetados de 6 a 20 kg durante dos ciclos completos de cría. Se almacenaron en un colector de datos valores diez-minutales de hasta 30 variables, entre las que destacan la temperatura, humedad, concentración de CO_2, velocidad del aire o la actividad animal.

Es precisamente la actividad animal, variable de estudio en esta tesis, para la cual se estableció un método de medición robusto, fiable y de bajo coste a través de sensores de infrarrojo pasivo. Se comprobó la validez de estas mediciones mediante su comparación con una observación directa de los animales. Se pudo

confirmar la concordancia entre los valores registrados por ambos métodos, con valores del Coeficiente de Correlación de Concordancia de 0,86 y correlación de Spearman de 0,90. Sin embargo, la precisión no fue constante a lo largo de ciclo, sino que ésta fue mayor al principio del mismo, cuando los animales eran más pequeños y ligeros. Posteriormente se realizó un análisis espectral de la serie de actividad mediante la Transformada Rápida de Fourier y la Transformada Wavelet Continua. De este proceso se confirmó la influencia de los distintos factores ambientales y de manejo sobre la actividad animal, como los períodos de luz/oscuridad o el horario de reparto de alimento. Además, se establecieron una serie de ecuaciones sinusoidales que definen la actividad de los lechones. En general, durante el ciclo los animales mostraron dos picos de actividad a las 10:00 y a las 18:00 h, con un período de reposo entre las 22:00 y las 07:00 h. Sin embargo, durante la primera mitad del ciclo se detectó un patrón de comportamiento con un único pico de actividad, debido principalmente a la menor competencia por el espacio en el corral. Finalmente, estos patrones de actividad fueron empleados en un modelo híbrido que combinó la Transformada Wavelet Discreta con Redes Neuronales Artificiales. Los resultados de este modelo, empleado para la predicción de la concentración de CO_2 en el alojamiento, muestran que la inclusión de la actividad junto con la temperatura de la sala y la exterior predicen el siguiente valor de concentración con una raíz del error cuadrático medio de 154 ppm. Además se detectó un retardo de casi una hora entre el momento de actividad y su respuesta en la concentración del gas. A pesar de todo, los mejores resultados predictivos se alcanzaron con un modelo autorregresivo, que empleaba valores pasados de la serie de CO_2, indicativo de la elevada inercia de esta variable.

A modo de conclusión se confirmó que el sistema de medición de la actividad a través de sensores de infrarrojo pasivo es un método fiable y económico que permite registrar los patrones de comportamiento de los animales. Estos patrones, o la propia actividad, pueden ser usados en modelos predictivos del clima en aras a lograr un control más eficiente de los sistemas de climatización.

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Chapter I: Background

1. INTRODUCTION

By mid-2017, there were around 7.6 billion inhabitants in the Earth, which means an increase of close to one billion during de last 12 years (United Nations, 2017). Currently, world population is still growing up, albeit more slowly, going from de 1.24% anually ten years ago, to the 1.1% nowadays. In this way, it is stimated that the population will grow by more than one billion people in the next 13 years, reaching 8.6 billion in the year 2030 and 9.8 in 2050. While the population is awaited to continue growing after the end of the 21st century, the growth rate is expected to decline.

On the other hand, more than half of the population growth is foreseen to occur in African countries with 1.3 billion mor inhabitants. It will be followed by the Asian continent with 750 million, while Europe is going to be the only region with less population in the year 2050. Therefore, population growth will be concentrated in less developed countries, which will make it difficult for governments to eradicate poverty, reduce inequalities, generalize education and health or fight hunger and malnutrition.

1.1 Socioeconomic context

A global economic growth of 2.9% per year is forecasted, which will help reduce abolute economic poverty in developing countries. There is also consensus among the experts to assume that the current trend will continue, and that developing countries will grow much faster than the developed ones, reducing relative inequalities in *per capita* incomes, but not in absolute differences (FAO, 2009).

Taking into account this forecasts, one of the great future challenges is to eliminate hunger and malnutrition problems, that can be aggravated by the increasing population. Although in the 2000-2013 period the population increased, the prevalence of undernourishment was reduced from 14.7% to 10.8%, understood as the percentage of population suffering from malnutrition. However, this rate has been reduced and even paralyzed between 2013 and 2015, evenmore, it is stimated that this percentage increased again to 11% in 2016, which means around 815 million people undernourished in the world. Therefore, humanity must face a series of efforts to eliminate hunger under increasing population environment. So, it is forecasted that the food production will also have to increase in a 50% in the year 2050 (FAO *et al.*, 2017).

This increase in food production will have to be carried out in a context in which most of the population is settled in an urban environment, which fewer and fewer inhabitants in rural areas, and therefore, with fewer farmers. Climate change is algo going to threaten the food production increase, as well as social conficts, natural disasters, pressure on the territory and a growing concern about the impact of agricultural in our environment.

One of the Susteinable Development Goals of the UN is “Zero Hunger” (PNUD, 2018). This aim tries to end all forms hunger and malnutrition by 2030, ensuring an universal access, specially children, to a sufficient and nutritious food all year round. This, in conjunction with the currently tendency towards the convergence in the diets of the societies, in terms of food patterns, bring up an increasing need of animal origin products.

Consequently, even though the fact that a decrease in meat consumption can and should be produced in more developed countries, the increase of the disposable income *per capita* in low and middle income countris will also increase the consumption of animal products. In that sense, it is expected a soar in food demand in the year 2050. For example in 2009, FAO estimated that the cereals production should increase around 900 million tons in 2050. Meanwhile, meat production will have to rise in more than 200 million tons to reach the 470 millions (FAO, 2009). It will be necessary to increase poultry production in 2.3 times, and between 1.3 and 1.8 times the meat of other livestocks. Pig meat production is estimated to have to increase to 140.7 million tons in the year 2050, which represents 137% of the production in 2010 (FAO, 2011).

This great demand for animal products will be mainly concentrated in large cities, which will have to be served in most cases by intensive production units of medium/large size. These units are characterized by their hability to increase the production per animal per unit of land per unit of time. Also, they allow the production of large quantities of animal proteins at a relative low price.

However, intesive livestock systems face differents threats or constraints on their way to increase production. The main conditioning is the environmental one, since it is a production with a big impact on the environment, both for the amount of consumed resources (water, raw materials, energy) and for the production of pulluting waste (greenhouse gas emissions or soil pollution). Other constraints as the increasing price of inputs may threaten the development of the sector. Finally, aspects such as the appearence of new contagious diseases, food security or the growing concerns in concepts like the animal welfare will undoubtedly condition the future of intensive livestock productions.

On the contrary, this intensive characteristic could helps the sector to build a more efficient system in terms of resources uses, facilitating a better management and a reduction of waste generated. The sector must bet on an intensive production that is able to provide sufficient and quality food, with a clear commitment to animal welfare and environmental respect. This will require the use of new technologies that allow the improvement of productive and energy efficiency.

1.2 Pig sector

The worldwide importance of the pig sector is beyond doubt, both from an economic and social point of view. In fact, pork accounted for 35.9% of the meat market in the world in 2017. With 118 million tons, it is in second place behind poultry meat (36.5%). In the world market, China is the main producer of pork with 45.7%, followed by the EU with 19.7% and the USA with 9.8%. Further, countries such as Brazil, Vietnam and Russia appear with barely 3% of world production each (FAO, 2018).

Precisely, in 2017, China was the main importing country with 2 million tons, representing 25.9% of total world imports. Then, Japan appears with 18.1% and Mexico with 11.2%. Among the main exporting countries, the EU stands out with almost 3 million tons and 34.7% of total exports, followed closely by the USA with 29.7%.

Within the European Union, it stands out the production of Germany with 5 million tons in the year 2017, which supposes 23.4% of the production of the EU. Second place, Spain has 4 million tons and a production share of 18.2%, followed by France, with 9.3%, and Poland, with 8.5%. Regarding the number of heads, of the more than 254 million heads slaughtered in the year 2017, 22.7% of the sacrifices were made in Germany, followed by Spain with 19.5%. Noteworthy is the increase in the production of kg of Spanish meat in the period 2013-2017, in which its production increased by almost 24%, compared to the German or French production that remained stable (FAO, 2018).

In this way, Spain is globally ranked as the fourth producer country behind China, the US and Germany. In terms of the livestock census, Spain ranks third in the world with 30 million animals after surpassing Germany in 2015. The census increase of the last campaigns was evident in all categories of animals, but especially in piglets (Subdirección General de Productos Ganaderos, 2018a). In the economic aspect, just the Spanish swine production supposed a movement of 6894 million euros in 2017, which represented 36.8% of the final livestock production, and 14.4% of the final Spanish agricultural production. In addition, in the same year 2017, the pig sector contributed to the maintenance of 300 thousand direct jobs and more than 1 million indirect jobs according to INTERPORC estimations.

Spain, therefore, is consolidated as a net export state, with a self-supply rate of 174% in 2017, with more than 2 million tons exported compared to less than 0.3 million tons imported. The main destination of Spanish exports is intra-community (65.8% of the total), especially France (22.7% of exports to the EU), Portugal (14.2%) and Italy (13.9%). Regarding non-EU exports, its specific weight increased in recent years, going from 20% in 2013 to 34% of total exports in 2017. In this last year the main destination was China (40% of the extra-community exports), followed by Japan (15.7%) and the Philippines (9.1%). Special mention deserves the case of Russia, which before the ban on European pig imports in 2014, imported 17.3% of Spanish extra-community exports.

Despite the leadership of the Spanish state in the pig sector, there is a non-homogeneous situation regarding the distribution of domestic production. For example, only two Autonomous Communities, Cataluña and Aragón, had 57.8% of the total number of heads in the state in November 2017 (28.9% each). Being Aragón, the community with the highest growth in number of animals compared to 2009 (40.7% increase). However, it was in Cataluña that the largest number of animals were sacrificed in 2016, with 42.9% of the state, compared to the 11.4% of Aragón. In this context, Galicia occupied the eighth position in 2016 with 82 tons of meat (2% of the state) and with more than 1 million animals registered (4.1% state), an amount that remained stable in the period 2009-2017 (-0.6%). A characteristic of the Galician sector is the large number of farms, with 32.6% of the total Spanish, which denotes the maintenance of traditional farms for family consumption (Subdirección General de Productos Ganaderos, 2018a).

In the Galician area, in 2017, the largest number of animals was located in the province of Pontevedra with more than 314 thousand heads, followed closely by A Coruña with almost 302 thousand and Ourense with just over 298 thousand animals. Further away, it was the province of Lugo with 182 thousand heads (Subdirección General de Productos Ganaderos, 2018a).

The strength of the pig sector at the state level lies in the high specialization of the farms, as well as in the great dimension of the same. Generally, large farms manage to be more efficient from a technical and economic point of view. Thus, while other European countries such as Portugal and Ireland have a structure in which closed cycle farms predominate, in Spain or Germany the sector is much more organized with specialized fatteners either in the finishing period or in the breeding period. For example, in 2010 in Spain more than 65% of the finishing pigs were in large specialized finishing farms (Marquer, Rabade and Forti, 2014).

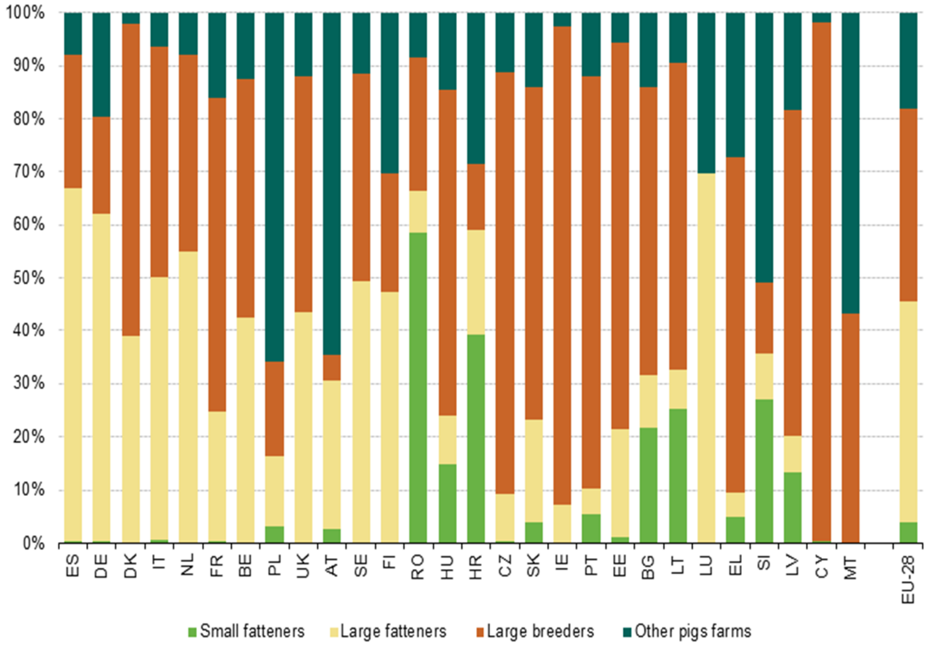

Figure 1: Distribution of other pigs by type of pig farm. *Small fatteners*: no sows and fewer than 10 other pigs; *Large fatteners*: no sows and at least 400 other pigs; *Large breeders*: at least 400 pigs and 100 sows. Source: Marquer, Rabade and Forti (2014).

This trend towards specialization continues to this day, since between 2007 and March 2018 the number of total farms decreased by 13%. Specifically, the number of small farms, according to RD 324/2000 (less than 4.8 UGM), were reduced by 45%. Meanwhile, the largest holdings belonging to group 3 (between 360 and 864 UGM) grew by 43% in the same period, although they still represent only 2.3% of the total. This process of concentration occurs in farms of an intensive nature. However, during the last years, there is an increase in the number of extensive farms located especially in Andalusia and Extremadura.

The specialization of the sector was the great bet of the Spanish meat industry, partly pushed by the reduced profit margins of the products. This situation forced the producers to reduce production costs, mainly by increasing the size of the farms. As can be seen in Figure 2, the production costs per kg of carcase were progressively reduced throughout the historical series, while the purchase prices continued to fluctuate in a cyclical manner with a global trend to the downside. For example, the crisis in the sector in 2015, which lasted until mid-2016, accelerated the closing of small farms and the least efficient ones. The year 2017 was a relatively good year of prices, although in the first quarter of 2018 the profit margins returned to negative values.

As a consequence, in order to increase the viability of the farms, it is required an improvement in their efficiency, by reducing costs mainly related to food, prophylaxis and energy.

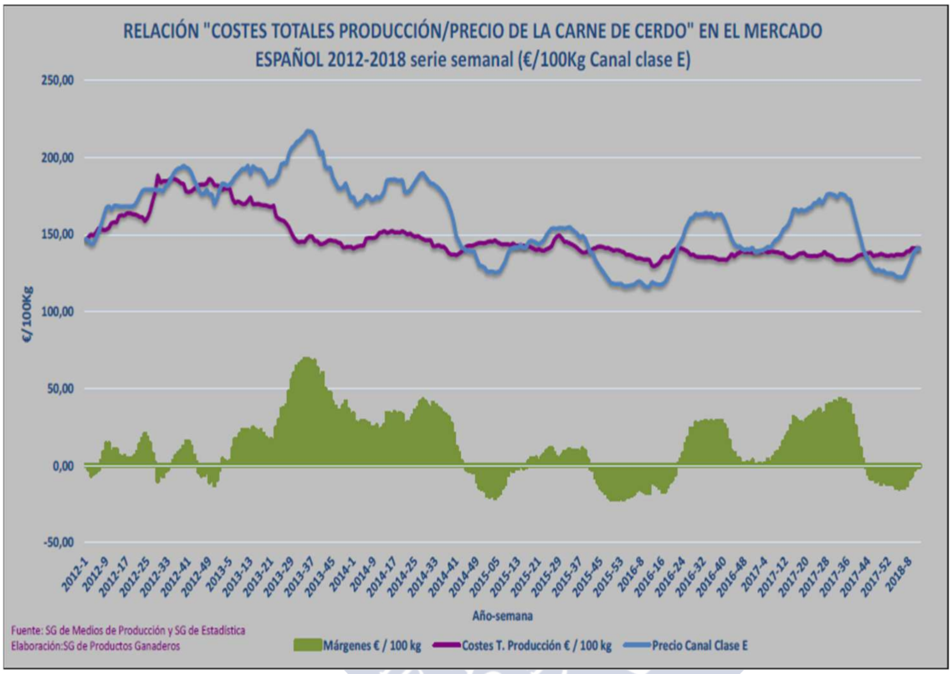

Figure 2: Profit margin of Spanish pig farms. Source: Subdirección General de Productos Ganaderos (2018b).

2. JUSTIFICATION OF THE THESIS

2.1 Environmental impact of swine production

The foreseeable increase in the demand for food products will bring with it an increase in pressure on natural resources, from deforestation of lands for cultivation to excessive use of water or environmental pollution. Currently, the livestock sector has already a high impact, since it uses 35% of the farmland and 20% of the water available in the soil (Macleod *et al*., 2013). In 2015, agriculture generated 426473 kilotonnes of CO_2 equivalent of greenhouse gases other than CO_2 itself, representing 10% of total EU emissions. Although at the European level, emissions have been reduced by 20% since 1990, Spain was along with Cyprus, the only member states that increased their emissions, mainly due to the growth of the bovine, pig and poultry sectors (EUROSTAT, 2016).

On the other hand, in the EU in 2015, agriculture was responsible for 94% of the ammonia emissions (3751 kilotons). Being this gas a precursor of the formation of aerosols in the atmosphere. Livestock is the source of 39% of global emissions (Galloway *et al*., 2004). Once again, there has been a reduction in emissions of 24% since 1990 at European level, except Spain, which increased its amount of ammonia emissions by 12%.

The global estimates of emissions of greenhouse gases in the pig sector are 9% of the emissions of the livestock sector, which places the sector as the second largest livestock originator of emissions, well behind the bovine. (EUROSTAT, 2016). The analysis of the life cycle in the pig sector chain indicates that animals are the main contributors to gas emissions (62.1%), compared to transport, distribution and commercialization (14.4%) and to consumers (23.5%). Of the activities related to animal production, the production of the concentrates is the main responsible for the emissions, followed by the handling of the slurry (Noya *et al*., 2017). It is precisely the anaerobic degradation of organic matter by bacteria, both in the digestive tract and in the slurry, the main source of methane (EUROSTAT, 2016). For nitrous oxide, it is originated only from slurry, and its formation occurs during an incomplete nitrification/denitrification processes performed by microorganisms that normally convert NH_3 into non-polluting molecular nitrogen (N_2) (Philippe and Nicks, 2015).

Similarly, pig farms are responsible in Europe for 25% of NH_3 livestock emissions. This gas comes mainly from the rapid hydrolysis of urea in the urine and faeces of animals. The hydrolysis of urea is catalysed by the urease enzyme, originating carbonic acid and ammonia (Sigurdarson, Svane and Karring, 2018). Ammonia emissions are concentrated mainly in livestock housing (50%) and at the time of distribution of slurry (30%). The fattening farms are responsible for the greatest amount of emissions (70%), while the sows and the piglets produce 20% and 10% of the emissions respectively (Philippe, Cabaraux and Nicks, 2011).

The formation and emission of these gases in farms is influenced by numerous factors, such as the type of facilities, management, indoor climate or animal activity. Blanes-Vidal *et al.* (2008), found a high correlation between ammonia emissions and daily animal activity of pigs, in part due to the relationship of this with the air flow ventilation and partly to the urinating behaviour of animals. Jeppsson (2002) also found a correlation between temperature and animal activity with NH_3 and CO_2 emissions, in such a way that the increase in ammonia emissions was exponentially related with the increase in temperature. Other factors, such as high air velocity over the surface of the pit, increase the transfer rates of gases to the environment (Blanes-Vidal *et al.*, 2012).

Therefore, in a farm, several actions can be carried out to reduce the emission of harmful gases. One of them is to optimize the use of the food, adjusting the composition of the diets to the specific requirements of the animals. The improvement of slurry management systems by separating the solid and liquid phase or the use of acidifiers can contribute also to this reduction. The reduction in energy consumption from non-renewable sources contributes positively too.

Another action that should be implemented to reduce polluting emissions by pig farms is the establishment of an adequate air conditioning system. The equipment involved must be coordinated properly avoiding energy losses. These systems must also adapt their operation to the conditions of the pen, controlling environmental parameters dynamically according to the real needs of the animals. Even though these actions may have a limited direct impact on the production of polluting gases, they do have on the emission patterns. So much so that, for example, a greater air flow ventilation brings with it an increase in emissions

(Hamon, Andrès and Dumont, 2012). In addition, proper climate regulation has benefits on the health, performance, welfare and behaviour of the animal, causing an indirect effect on the level of emissions. For example, a bad thermal regulation will originate a response in the animals altering their preferences for the excreting and lying areas (Haeussermann, Hartung and Jungbluth, 2005). This relationship can reach such a point that, at high temperatures, the dirt of the pens increases linearly with the temperature, while increasing the level of air pollution (Aarnink *et al.*, 2006).

There are recent emission mitigation techniques that consist in the extraction of the air from the head of the pits. This way, up to 43% of the ammonia emitted can be retained and prevented from spreading through the housing (Saha *et al.*, 2010). With this system, it is possible to extract air with concentrations up to 20 and 30 times higher than those achieved with ventilation in the room, especially in ammonia and amines, even using low ventilation flows (Van Huffel *et al.*, 2016). In this way the air quality in the housings is improved, and allows a more efficient treatment of the extracted air by means of filtering techniques with the aim of reducing its polluting power (Hansen *et al.*, 2012).

2.2 Animal welfare in the pig sector

Joined with the reduction of the environmental impact of the farms, the protection of animals and their welfare will be one of the main challenges for the sector. In addition to the growing and restrictive legislation on animal welfare, market pressure has guied, and will continue to do so, the transformations that the sector must adopt. This is reflected in the 2015 Special Eurobarometer "Attitudes of Europeans towards Animal Welfare", which shows that 94% of Europeans agree with the idea that it is important to protect the welfare of farm animals (57% they consider it very important). Even 82% of European citizens consider that it would be necessary to increase this protection. Finally, 59% say they are willing to pay an extra price for products derived from production systems that respect welfare.

Aware of the progress of these mindset, the European Commission has been collaborating with Member States for over 40 years with the intention of improving the living conditions of farm animals. In 1974, the first legislation on animal welfare in slaughterhouses took place. In 1998, the Council Directive

98/58/EC was passed, which legislated the basic matters for the protection of intensive livestock. The concept of animal welfare on which this legislation is based and which is widely accepted as a definition is the so-called "Five Freedoms":

1. Freedom from hunger and Thirst;
2. Freedom from discomfort;
3. Freedom from, pain, injury or disease;
4. Freedom to express normal behaviour;
5. Freedom from fear and distress.

The Treaty on the Functioning of the EU, in its Article 13, also includes the need for the Union and the Member States to take into account the requirements regarding the welfare of animals during the planning and application of policies.

The welfare of animals in swine production is currently ensured by the Council Directive 2008/120/EC, addressing issues such as the characteristics of facilities, spaces, feeding, management or training of operators. In Spain, the current legislation on animal welfare in the pig sector is regulated by the RD 1135/2002, amended by RD 1392/2012 in order to adjust it to the new regulations. All these regulations place special emphasis on the control of the indoor environment and air quality, as well as the availability of space for animals. The provision of materials that allow them expressing their behavioral needs and the limitation of actions on animals that may affect their welfare, especially mutilations (castration or tail docking), are also regulated. These conditions and requirements are especially compromised in the current intensive systems.

Of the so-called "Five Liberties", several studies have focused on the influence of their limitation on the welfare of pigs and therefore on the productive performance of the same. The deprivation of food or water has a direct and clear effect on the welfare and performance of animals. Although it is not the interest of any farmer to subject their animals to hunger or sedentary periods, these situations can appear in cases of strong social competition, weak healthy condition, extreme environmental conditions or even associated with abrupt changes such as the weaning period (Quiniou *et al.*, 2001; Dybkjaer, Jacobsen and Togersen, 2006). The absence of diseases, pains or injuries also has a direct impact on productive performance and animal behavior, from the reduction of mortality ratios to better food indexes (Escobar *et al.*, 2007, Pastorelli *et al.*, 2012). To continue with, having the ability to express pig natural behaviors, such as digging into the ground, reduces injuries and aggressive behavior among animals (Nannoni *et al.*, 2016, Bracke, 2017), thus achieving better welfare and social cohesion. In this case, good management of the enrichment objects is of great importance in pigs (Scott *et al.*, 2006, Da Silva, Manteca and Dias, 2016). On the other hand, the breeding of animals under conditions of continuous stress or fear, such as those created by hostile management, can have repercussions on reproductive and productive parameters (Sommavilla, Hötzel and Dalla Costa, 2011). Finally, creating the right conditions of comfort, providing the animals with an adequate environment with areas of refuge and rest, seems like a key element to ensure welfare situations in animals. Here, the design of the facilities and the management of the environmental parameters will define the achievement or not of an adequate well-being. It is logical to think, for example, that very high temperatures or humidities will reduce the comfort of pigs, and therefore these will increase the response mechanisms against stress situations, mechanisms that normally go through alterations in the normal behaviors (Collin *et al.*, 2001; Debreceni *et al.*, 2014).

Since animal welfare is a multidimensional concept, which includes both physical and mental aspects, the determination of the level of well-being is a task that can involve a high degree of subjectivity. This is because the importance given to different aspects of well-being may be different for each person. This is why there are numerous works that attempt to make an overall assessment of well-being based on objective measurements (Welfare Quality®, 2009, Jongman, Hemsworth and Skuse, 2014, Brandt *et al.*, 2017), based mainly on indicators of animal origin and not exclusively in the facilities or in the environment as it had traditionally been done. Therefore, it is the animal itself who should tell us about the welfare state through measurements of its behavior. However, these indices are calculated based on stady observations, it would be interesting to make valuations for longer periods of time. Thus, together with the climate data of the buildings, information such as the consumption of water and feed or the levels of animal activity, would play a fundamental role in that determination.

2.3 Environmental control in pig farms

As is evident in the previous sections, the environmental conditions of the livestock buildings and their management have direct repercussions, both on the levels of polluting emissions and on the welfare of the animals. Consequently, it influences the productive performance of farms. This statement is especially important in intensive farms with forced ventilation systems, which will be the type of farm object of study in this doctoral dissertation.

Therefore, ensuring adequate environmental conditions according to the needs of the pigs at all times is a priority task. The control techniques for these variables depend on the air conditioning systems available on the farm: natural or forced ventilation, hot water or electric heating systems, cooling systems and even air filtering equipments. Logically, it is easier to achieve better control in those buildings where there are forced ventilation equipment accompanied by heating and/or cooling systems. Even so, the key part of these systems is the controller that must coordinate and manage the different facilities. This control can be done in different ways, from the classic techniques of "local control" such as the all-or-nothing systems or the popular PID control algorithms (Proportional, Integral and Derivative), to more sophisticated "supervisory control" techniques such as Fuzzy Logic Control or Predictive Control (Model Predictive Control, MPC) (Afram and Janabi-Sharifi, 2014). Due to the relative simplicity of the air conditioning systems used in pig farms, PID control is the most widespread method among current controllers, since it allows basic control and automation functions that largely satisfy the objectives (Dong and Lam, 2014). On the other hand, the industry was traditionally reluctant to adapt complex control methods, it is also for this reason that most air conditioning systems still employ very simple controllers (on/off, PID) instead of more modern controllers like the MPC (Killian and Kozek, 2016).

It is precisely the MPC, together with artificial intelligence, one of the most promising techniques due to its ability to integrate the rejection of disturbances, the management of constraints, a dynamic control and strategies of energy conservation in the approach of the controller (Afram and Janabi-Sharifi, 2014). Research has shown that the use of an MPC controller in a plant can mean from 7% to 50% savings in energy consumption with respect to the most basic controllers. The MPC control algorithm is based on the use of a system model to predict its future state, and then generate control vectors that minimize a certain cost function over the prediction horizon, taking into account the presence of restrictions and disturbances (Afram *et al.*, 2017). In the case of livestock facilities, these restrictions could be related to the reduction of the level of emissions, an increase in thermal comfort and a reduction in energy consumption.

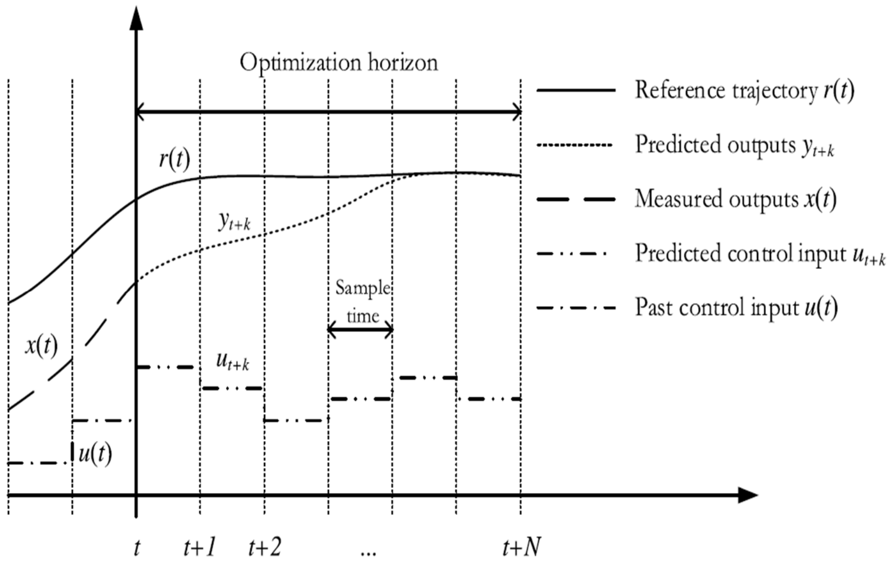

Figure 3: Diagram of Model Predictive Control. Source: Afram *et al.* (2017).

In all predictive control algorithms, identification and modeling are the most expensive and determinant steps of the process. Achieving reliable predictions are crucial for good MPC performance. These models must meet basic conditions that are: simplicity, good estimation of system dynamics and good predictive properties (Prívara *et al.*, 2013). The need for specific models for each system is probably the reason why the MPC is not yet an algorithm widely adopted by the industry. The so-called black-box models, or "data-driven models", can greatly simplify this process. These models are developed by *in situ* measurements of the necessary inputs and outputs of the system and the subsequent adjustment of a mathematical function to estimate the functioning of the system (Killian and Kozek, 2016).

Therefore, the research efforts for the effective development of predictive control algorithms in the primary sector should focus on the design of simple, versatile and precise models, as is already happening in other fields (Liang and Du, 2005; Huang, Chen and Hu, 2015; He *et al*., 2016). In this sense, in the livestock sector, it would be especially useful to include exogenous variables of animal origin, such as activity levels, water and feed consumption, weight or age of the animals. In this way, the control algorithms could be able to understand the state of the animal at any time. Thus, they would adapt their responses to the needs of the livestock, without doing that only based on a set of ventilation instructions at the beginning of the production process.

2.4 Animal activity as an indicator

Animal activity, understood as the movement of animals, varies throughout the day (de Sousa and Pedersen, 2004, Blanes and Pedersen, 2005, Schauberger *et al*., 2013). This, together with the animal weight and temperature, constitutes one of the main responsible for the modification of the pen environmental conditions due to its influence on the production of CO_2 or NH_3, dust, heat, humidity, etc. Due to the aforementioned relationship with the health status and welfare of the animals (Broom and Corke, 2002; Huynh *et al*., 2005), the environment of the buildings (Brown-Brandl *et al*., 2004; Pedersen, Jørgensen and Theil , 2015), and with the emission of polluting gases (Blanes-Vidal *et al*., 2008, Estellés *et al*., 2010, Ngwabie, Nimmermark and Gustafsson, 2011), activity or animal behavior is one of the most promising variables for inclusion in the climate control systems of livestock housing (Youssef, Exadaktylos and Berckmans, 2015). Despite these efforts, few studies have set their objective to define the physical activity of the animal, even knowing that its behavior follows biological cycles of around 24 hours (Villagrá *et al*., 2007), including periods of rest and activity. In the last one, the movement of animals is not constant, instead of that, it presents peaks of activity, usually influenced by environmental factors, management, health, age or social behavior (Quiniou *et al*., 2001, Pedersen, Jørgensen and Theil, 2015).

However, currently, this parameter does not take part, in a generalized way, of the environmental control facilities in pig farms. Even so, the market already offers an integrated system of management and monitoring of weaned piglets and fattening pigs of the Danish company Skov A/S, the ProGrow system. This system includes among its measurements those of water and feed consumption, as well as an estimation of the weight of the animals through video cameras, a methodology already described in the bibliography by (Kashiha *et al*., 2014).

3. THEMATIC COHERENCE OF THE THESIS

The thematic justification of the present thesis is argued in the previous epigraphs. They describe the importance and possibilities of the variable of animal activity for the improvement of environmental control of pig farms. Furthermore, the structure of this doctoral thesis document is based on the actual evolution of the work carried out during the PhD programme. It contains three chapters, corresponding with the three scientific publications required to complete the doctoral programme under the modality of compendium of articles, according to the norms of the University of Santiago de Compostela. The research work began with a thorough review of the most relevant scientific publications in the research area. This revision continued throughout the period of the PhD, as progress was made in the study of animal activity and in the different techniques employed in it. The relevance and timeliness of the bibliographic citations present in the text reflect this exhaustive job.

Once acquired a sufficient level of scientific knowledge of the current state of the matter, the experimental study was designed based on the objectives proposed in the work plan and the available equipment. In an exploitation of weaned piglets, ten-minute measurements of different environmental variables were made during two complete cycles. Among the proposed objectives, the main challenge involved the measurement of animal activity in real time in groups of animals. It was decided to opt for a simple, economical and adaptable measurement such as measurement through passive infrared (PIR) sensors, which can be easily implemented in commercial farms. Chapter III bring us the results of the adaptation of the measurement method designed by Pedersen and Pedersen

(1995). In it, the validity of the activity data collected in the conventional swine farm object of the test is evaluated by comparing it with a human observation of the activity by means of recording.

Once the aptitude of the animal activity measurement system installed in the conventional piglet farm was verified, an analysis of the series obtained by different techniques was carried out. As a result of this work, a publication corresponding to Chapter IV was published. The evolution of the activity of the animals during a complete breeding cycle was evaluated. The use of the Fourier Transform and the Wavelet Transform Continuous on the series of animal activity allowed obtaining patterns that define the behavior of the piglets during the cycle.

Following the logical evolution, these activity patterns were implemented in predictive models of the environment in the building. Thus, the publication of Chapter V evaluates the performance of a hybrid model that combines the Discrete Wavelet Transform with Artificial Neural Networks for the prediction of CO_2 concentration in livestock buildings.

4. OBJECTIVES

The general objective pursued by this thesis is to achieve an improvement in animal welfare and the energy and production efficiency of pig farms in the weaning stage. During this period, the weight of the piglet triples in a short period of time, the demands of animal welfare are high, and the environmental requirements show important variations. Consequently, environmental control systems must adapt to the growth needs of animals. Therefore, it is intended to generate management tools and control strategies for the automation of air conditioning installations, susceptible to being implemented in conventional programmable controllers and capable of improving animal welfare. Focusing in the work to be developed, the possibilities of integrating the animal activity variable in the incipient systems of predictive environmental control will be evaluated. For such work, the specific objectives of this thesis are:

1. Design a system of continuous measurement of animal activity in a piglet farm from 6 to 20 kg, which should be simple, robust, reliable and low cost for the farmer. Its operation will also be evaluated, highlighting the advantages and disadvantages of its use with respect to other currently available systems.

2. Analise the recorded variable by the measurement system, during a complete breeding cycle of the animals, studying their behaviour and its possible causes. This will allow to establish sinusoidal patterns of daily activity.

3. Establish predictive models of the environment in livestock buildings based on animal activity, in order to establish relationships between variables. In turn, the designed models should be capable of being implemented in advanced climate control algorithms.

The achievement of each of these goals is reflected in the following publications, which constitute the body of this PhD thesis. In addition, each of these articles constitutes a separate chapter in this document:

<u>Objetive 1; Chapter III</u>: Besteiro, R., Rodríguez, M. R., Fernandez, M. D., Ortega, J. A., & Velo, R. (2018). Agreement between passive infrared detector measurements and human observations of animal activity. Livestock Science 214C (2018) pp. 219-224. https://doi.org/10.1016/j.livsci.2018.06.008.

<u>Objetive 2; Chapter IV</u>: Besteiro, R., Arango, T., Rodríguez, M. R., Fernández, M. D., & Velo, R. (2017). Estimation of patterns in weaned piglets' activity using spectral analysis. Biosystems Engineering. https://doi.org/10.1016/j.biosystemseng.2017.06.014.

<u>Objetive 3; Chapter V</u>: Besteiro, R., Arango, T., Ortega, J. A., Rodríguez, M. R., Fernández, M. D., & Velo, R. (2017). Prediction of carbon dioxide concentration in weaned piglet buildings by wavelet neural network models. Computers and Electronics in Agriculture, 143, 201-207. https://doi.org/10.1016/j.compag.2017.10.025.

Chapter II: Materials and methods

1. LIVESTOCK BUILDING

All the measurements and analyzed parameters in this doctoral thesis were taken during two breeding cycles in a swine farm of weaned piglets from 6 to 20 kg located in the northwest of the Iberian Peninsula. Specifically, the farm is located in Toques, A Coruña. It has a maximum capacity of 5971 piglets of 20 kg, distributed in two contiguous buildings in "L" form and with five and three rooms of weaning respectively. The edifices have a total dimensions of 69.8 x 14.5 m^2 and 31.9 x 14.9 m^2 respectively, following a similar interior arrangement both of them, with a lateral corridor of 1.2 m wide with access to the successive weaning rooms.

Figure 4: Aerial view of the piglet farm where the measurements were taken.

The configuration of the rooms is similar in all of them, and as described in depth in Chapters III, IV and V, each one has two corridors that serve four corrals on each side, with PVC dividing panels and a fully polypropylene slatted floor. Each room contains 16 pens of 3.2 x 3.2 m2, with maximum capacity for 50 piglets each. In addition, each room is equipped with an air extraction system and a heating system. The renewal of air is done from the side windows placed on both sides of the rom. The air exit the room through a chimney arranged in the central area of the chamber. The air inlet and outlet sections are regulated automatically. A heating plate of hot water (3.20 x 0.50 m) under a PVC roof placed at a height of 0.70 m composes the pen heating system. Piglets were fed ad-libitum with compound feed. Water was supplied at a nipple drinker placed close to the feeder. In addition, the farm has other additional facilities such as:

1. double perimeter closure,
2. changing rooms, showers and toilets,
3. drive-through disinfection bath
4. four vertical feed storage silos of polyester,
5. groundwater collection point with chlorination system,
6. warehouse of products and office,
7. outer slurry storage pit.

2. MEASURED VARIABLES

In this farm, measurements were made of different parameters, both environmental and animal, that were used to a different extent in this PhD thesis. Table 1 shows the variables measured together with their position, measurement equipment and periodicity of the measurements. In total information was recorded of two complete weaning cycles of 40 (June 9 - July 19) and 38 (February 27 - April 6) days of duration. The external conditions were also measured. A total of 33 environmental and animal variables were measured. From the set, 30 were measured continuously, making measurements every second and storing the ten-minute average. The feed intake was obtained daily, and the two remaining variables, body mass of the animals and height of the level of slurry in the interior pit, were measured weekly.

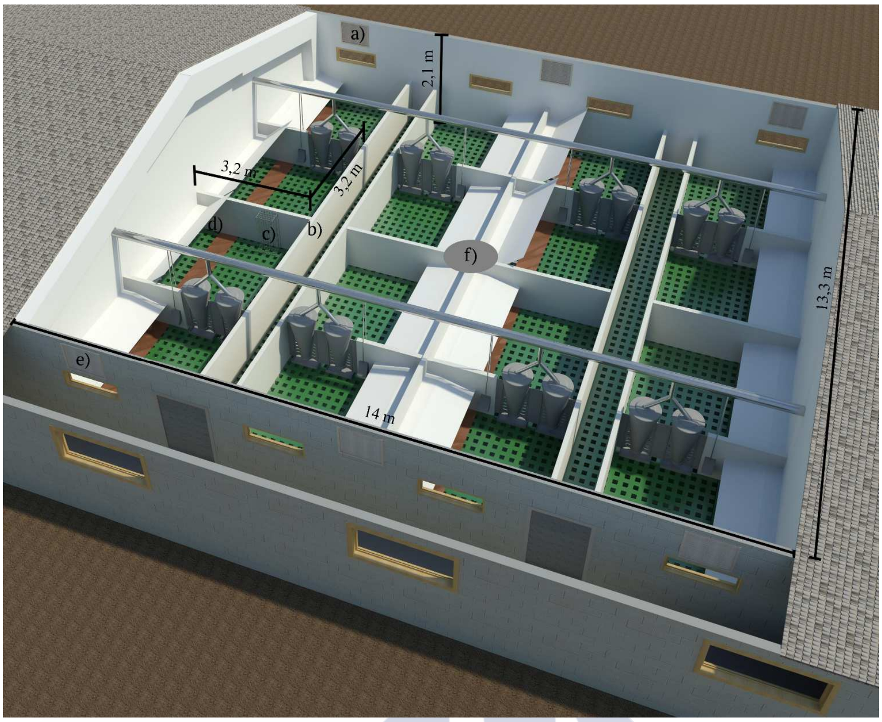

Figure 1: Weaning room for piglets where measurements were made with the location of the sensors used. a) air inlet 1 (AI 1); b) PIR and Video Camera; c) animal zone 1 (AZ 1); d) animal zone 2 (AZ 2); e) air inlet 2 (AI 2); f) air outlet by chimney located at 2.8 m height (AO).

Between the 30 variables recorded, 23 of them were taken inside the building. Specifically, the measurements were made in a farm room in three different positions: the animal zone, differentiating two subzones within it, one below the climatic cover (AZ2), and another outside the cover (AZ1); in the entrances of fresh air from the lateral corridor of access to the rooms (AI1) and from the outside (AI2); and in the air outlet of the room (AO). To protect the sensors installed in AZ1, they were placed inside a cage and at a height of 20 cm from the ground. All ten-minute measurements were stored in two data collectors, HOBO® and Campbell Scientific Ltd. CR-10X. The remaining 7 variables correspond to data from the outside of the farm (EX), recorded by a weather station located on the plot itself.

Table 1. Measured variables with their position, equipment and measurement range.

Variable	Position	Model	Range
CO_2 concentration	AI 1 AZ 1 AO	Delta Ohm HD37BTV.1 with infrared tecnology (NDIR) with double wave length	0 - 5000 ppm
Temperature Relative Humidity	AI 1 AI 2 AZ 1 AZ 2 AO	ONSET® S-THB-M002	-40 - 75°C 0 - 100%
NH_3 concentration	AZ 2	Murco© MGS 150. Electrochemical sensor.	0 - 100 ppm
Air speed	AZ 1	Delta Ohm HD103T.0 omnidirectional hotwire probe.	0,08 - 5 m/s
Animal activity 1,3 (2 pulses in 20 s) Animal activity 2,4 (4 pulses in 20 s)	AZ 1 AZ 2 AZ1 AZ2	OPTEX© RX-40QZ. Passive infrared detector.	Cover area $12 \times 12\ m^2$, with 78 subzones
Water intake Feeder water intake	-	Elster M170 con pulse emitter Retrofit M170.	0 - 3 m^3/h
Temperature Relative humidity Wind speed Wind direction Gust speed Pressure Solar radiation	EX	HOBO® Weather Station equiped with S-THB-M002, S-WSB-M003, S-WDA-M003, M-CAA, RS3-B.	-40 - 75°C 0 - 100% 0 - 76 m/s 0 - 355°
Noise	AZ 1	Cirrus Research plc CR:822B	21 dB - 140 dB
Lighting	AZ 1	Nesa srl Lux-A	0,02 - 2 klux
Body mass	-	Digital scales MI2000	0 - 500 kg
Feed intake	-	Manual	-
Slurry level	-	Manual	-

It is outside the object of this thesis the analysis of all the variables collected during the trial. However, a great majority of them were taken into account in the initial processes of characterization of the cycles, in the search for interactions between variables and in the analysis prior to the publications finally achieved. As a result of this work and other complementary works, other publications arose parallel to the development of this document. These are three articles in popular science magazines of the sector, one in Portugal, and six publications in national and international congresses.

3. TECHNIQUES USED

Throughout the Chapters of this document, different techniques of analysis of the collected data series will be used, whose basis is detailed in the corresponding sections. However, since it is outside the scope of this doctoral thesis, there is no in-depth development of the different methods. The following is a brief enumeration of the techniques used, their purpose within each work and the bibliography consulted.

Chapter III deals with the validation of the PIR measurement system in front of a human observation of the animals. For validation, only statistical techniques were used in order to analyze the concordance between the data obtained by the two measurements. Human observation was taken as a reference method. The statistical techniques used, Spearman's rho correlation coefficient (ρ), the Concordance Correlation Coefficient (CCC) and Bland Altman's graphic method are perfectly defined in the Material and Methods section of the mentioned chapter (Bland and Altman, 1986, Lin, 2016).

In Chapter IV, in which the animal activity patterns were established, two different techniques of spectral analysis were used, the Wavelet Continuous Transform (CWT) and the Fast Fourier Transform (FFT). Through the CWT the series of animal activity in the continuous time-frequency spectrum was analyzed. This way, their behavior was studied throughout the entire cycle. Numerous technical documents were consulted to gain an in-depth knowledge of the fundamentals of this analysis, among which we can highlight: (Marchant, 2003, Neild, McFadden and Williams, 2003, Singh *et al*., 2010, Rosch and Schmidbauer, 2014). The FFT for its part was used to obtain the sinusoidal equations that define animal activity patterns, consulting more theoretical information about it (Bloomfield, 2000, Wilks, 2006, Shumway and Stoffer, 2011).

Finally, in Chapter V, a hybrid model was designed to predict the concentration of CO_2 in the livestock buildings. For this, a previous filtering technique was combined with a predictive model of the branch of artificial intelligence. Specifically, the Discrete Wavelet Transform (DWT) and the Artificial Neural Networks (ANN) were employed. The previous filtering of the series used in the hybrid model was done by the DWT. It differs from the CWT in the way of discretizing the scale parameter, in a manner that the CWT allows a more detailed analysis than the DWT, although more expensive (Nason, 2006; Liu, 2010; Joo and Kim, 2015). Finally, the ANN takes advantage of the filtering done by the DWT on the data series to predict the CO_2 concentration. Thus, achieving the so-called Wavelet-Neural Network (WNN) hybrid model. (Rojas, 1996, Nourani *et al*., 2014, Alizadeh and Kavianpour, 2015).

To carry out the aforementioned data processing and analysis, a computer with an Intel® Core ™ i3-2100 processor of 3.10 Ghz, with 4 GB RAM memory and Windows 10 operating system was used. In addition, a free version of the RStudio software, an integrated development environment for the programming language R, was used as a basic support for this thesis. It was also used the license of the University of Santiago de Compostela for the use of commercial software Microsoft® Office (MO Word, Excel and Access) and the license managed by the Spanish Foundation for Science and Technology (FECYT) for access to the Web of Science and SCOPUS platforms. Finally, the free Mendeley bibliographic management tool was also used.

Chapter III: Agreement between passive infrared detector measurements and human observations of animal activity

Chapter IV: Estimation of patterns in weaned piglets' activity using spectral analysis

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Chapter V: Prediction of carbon dioxide concentration in weaned piglet buildings by wavelet neural network models

Chapter VI: General discussion

The influence of animal activity on environmental parameters, and as evidence of the welfare status, arouses interest in this variable as a possible tool for environmental management in intensive livestock farms. This has not happened so far, partly due to the resistance of the industry to the inclusion of new complex control methodologies (Killian and Kozek, 2016), as well as to the difficulty and cost that its measurement may entail in modular farms.

In this document, we start by evaluating the validity of an adaptation of the activity measurement system proposed by Pedersen and Pedersen (1995). Firstly, the position of the PIR sensor was defined based on the characteristics of this equipment, looking for the movements of the animals were mostly in the direction perpendicular to the sensor. In addition, the location, height and orientation was choosen in order to cover the entire pen. The PIR system developed here, which avoids the analog treatment of the signal, shows good measurement results if we take human observation as a reference, with a Pearson correlation coefficient of 0.90 and a CCC of 0.86. Although with different PIR measurement systems, Puppe, Schön and Wendland (1999), and Langbein *et al.* (1996), found significant correlations $\rho \approx 0.83$ and $r^2 = 0.75$ with the human observation and the occupation time of a certain zone respectively, the latter in mouflon in freedom. We also detected a slight overestimation of 2.59% of the PIR with respect to human observation. However, this precision is not constant, it undergoes variations throughout the cycle, mainly related to the increase of mass and volume of the animals. Measurement are more reliable when the animals are smaller. Also during the night period, the lower activity rate and lower temperatures (Villagrá *et al.*, 2007) favor the accuracy of the measurements made by the PIR sensor.

Comparing the method with others present in the bibliography, such as the video analysis, it also obtained a Spearman correlation of 0.92 with respect to a human observation (Ott *et al.*, 2014), a very similar value to the one found here. A direct comparison between the methods carried out by Nielsen (2003) points towards a higher accuracy of the PIR detectors, mainly in the detection of low intensity activities. Therefore, although both methods are valid for the measurement of animal activity, PIRs are low cost detectors, strong, reliable and less technically complex. The advantages of video analysis reside mainly in their possibilities to distinguish between behaviors or even between areas of the pen (Costa *et al.*, 2014). Also, new algorithms have been developed to estimate the body mass or water consumption (Kashiha *et al.*, 2013, 2014).

The system generates a series of ten-minute data that defines the total time of activity recorded in that period. The analysis of this data series again justifies the validity of the method through the activity patterns obtained, which are very similar to others described in the literature for the same species (CIGR, 2002, Villagrá *et al.*, 2007; Schauberger *et al.*, 2013). This analysis reflects the influence of weaning on animals, which show high levels of activity during the first five days post-weaning, caused by the stress generated by the separation from the mother, the change of the diet type or the establishment of new social hierarchies. After this initial stage, activity levels stabilize until the last third of the cycle. In this last period, the activity is progressively reduced again, due to the increase in the kg m^{-2} ratio, and the consequent reduction of the available space per animal.

Knowledge of the levels of animal activity throughout a whole cycle is of interest from the point of view of animal welfare, or also for the early detection of diseases in situations of abnormal behavior (Kristensen and Cornou, 2011), as Madsen and Kristensen (2005) has already done with water intake. But the greatest interest lies in the analysis of daily behavior. The decomposition in sinusoidal waves of the daily behavior of the animals. In that sense, using the FFT, reflects the influence of the periodicities of 24, 12 and 8 hours in the composition of a pattern with two peaks of daily activity, at 10:00am and 6:00 pm, and a clear resting period from 10pm to 7am. These periodicities correspond to the day/night cycles (Debreceni *et al.*, 2014) in the case of the 24-hour harmonic; with the influence of the midday high temperatures in the case of the harmonic of 12 h (Costa *et al.*, 2014); and with the food distribution schedules for the third harmonic. This reflects the importance of three basic factors that define the activity, the circadian rhythms of the animal, the climate and the animals' management by the farmer. But this pattern with two peaks was not constant during the whole cycle. Instead, CWT has shown that during the first half of the weaning stage, the animals show only one peak of daily activity, and two peaks in the second half cycle. This fact has a multifactorial explanation, such as the greater availability of space during the first weeks together with a greater attitude towards the game (Spoolder *et al*., 2012), or a greater sensitivity to high temperatures when animals are younger (Bracke, 2011).

Obtaining sinusoidal activity equations allow the definition of daily animal behavior patterns, susceptible to be used in environmental control algorithms or real-time management systems. For example, for the prediction of the CO_2 concentration inside livestock buildings, the activity plays a fundamental role since it is the main source of its generation (Zong *et al*., 2014). In the WNN hybrid model established in this thesis, animal activity was selected as a predictive variable by the algorithms of variable selection. Specifically, the activity values were selected with a delay of 40 and 50 minutes for the prediction of the next CO_2 value. This fact shows an inertia of approximately one hour in the concentration of this gas. That is, current animal activity will have an impact on the gas concentration one hour later. In addition to the animal activity, the model also takes into account the current and the outdoor temperature with one, two and five delays. Aslo, the current and 20 minutes earlier temperature in the animal zone were chosen. The importance of the outdoor temperature in this CO_2 prediction model is related to its close connection with the ventilation flows, responsible for renewing the air (Jeppsson, 2002). In the case of the temperature in animal zone, it can also be explained by the ventilation flows, in addition to the influence on the slurry emission ratio (Ni *et al*., 1999). Both variables have a more immediate effect on air quality, symptomatic of an efficient ventilation.

The predictive results of this model, which employs DWT as a filter, are very promising, with a Pearson correlation of 0.89 and root mean square error (RMSE) of 154 ppm. However, due to the high autoregressive condition of the CO_2 series, the best predictive results are achieved with a WNN hybrid model in which the current and immediately previous value of the series itself is used, as well as the current outside temperature. With this model, the predictive results improve up to a correlation of 0.99 and RMSE of 26 ppm. This model surpasses the performance of the predictive model of Sun *et al*. (2008) for air quality in pig farms. The good performance of this hybrid model lies in the pretreatment of the data series with the DWT and the robustness of the ANNs. The decomposition of series into different subseries allows the model to cope with greater guarantees of success to non-stationary or trend series (Nourani *et al*., 2014).

Chapter VII: Conclusions

1. CONCLUSIONS

The work developed in this doctoral thesis allows expanding the knowledge of the animal activity in the weaned piglet's farms. It had been taken as starting point the developed and the validation of the performance of the measurement system, PIR sensors. Then it developed activity patterns based on a long period of measurement, analysing the factors and causes of animal behaviour. Finally, the possibilities of including animal activity in the incipient control systems were evaluated, that it could be able to include the animal status in the decision making process. The specific conclusions that it can be drawn from this thesis are:

1. The use of a system for measuring animal activity based on the use of PIR sensors allows precise data of animal behavior, in a simple, economical and robust way. Even so, as happens with other methods, the accuracy is slightly affected in conditions of high activity and high density of animals.

2. The data obtained through the PIR detectors allow to establish generic sinusoidal patterns of behavior, with two peaks of activity and a night rest period. However, parameters such as lack of space, thermal requirements or the animals' age made the behavior of the animals change throughout the cycle studied. It evolved from the initial purely sinusoidal daily patterns, with a single peak of activity, to the patterns, at the end of the cycle, with two daily maximums.

3. The inclusion of the animal activity variable in predictive models of the indoor environment of the livestock housing helps to improve its performance, as demonstrated in the hybrid model Wavelet - Neural Network hybrid developed of CO_2 prediction. It was also found that the effect of the activity did not immediately affect the CO_2 concentration in the livestock housing, contrary the influence was perceived almost an hour later. Even so, due to the high inertia of the gas in the housing, the autoregressive hybrid model was the one that obtained the best predictive results.

2. FUTURE WORKS

Given the good response of the PIR measurement system, and the mentioned importance of animal activity in intensive farms, it is proposed to continue the work done in this thesis through the development of predictive climate models, trying to get more predictions reliable in the long term and adaptable to changing conditions. Once this has been achieved, the inclusion of these models in climate control algorithms such as Model Predictive Control (MPC). This fact will allow to optimize the use of energy, reduce emissions to the environment and maximize environmental comfort, also, it will help the development of controllers more efficient and effective in livestock buildings. In addition, more emphasis should be placed on the need of including in these controllers the status and actual requirements of livestock. This can be achive using animal variables such as animal activity, health status, age, water or feed intake or animal weight.

Regarding this topic, an opportunity to design and implement systems of early disease detection through the analysis of the animal activity disturbances is also opened.

Chapter VIII: References

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