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Energy use for climate control of animal houses: the state of the art in Europe

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Abstract

Animal rearing is done into houses where heating, cooling, ventilation and lighting are adopted to control the indoor climate, however there are not reference values for the energy performance of such enclosures. In this paper, a first analysis on the energy use for climate control of animal houses that can be found in the technical and scientific literature is done for broilers, hens and pig houses, deriving reference energy use values that may be used for the benchmarking of the performance of these buildings.

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Keywords: livestock houses energy consumptions; literature review; indoor environmental control for animal production; broiler, laying hen, swine and dairy cow breeding.

1. Introduction

Since 2002 the EU legislation has set out stringent requirements in order to certify and promote the improvement of the energy performance of buildings through the building energy certification. However, in case of livestock housing, most of the requirements of EU legislation are dealing with the animal welfare related to the type of housing [1, 2], without considering aspects directly related to the energy performance of the enclosure. Even though some certification programs have been developed for specific products that are used in livestock houses (e.g. fans for

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climate control are now certified following the ErP – Energy related Products – Directive 2009/125/CE), there is not an energy performance scheme for assessing the energy performance for the climate control of livestock housing. This is particularly important in case of houses for swine and broilers, where there is a significant energy use for ventilation, heating and cooling of the indoor environment with variable schedules. In fact, breeders have the need to know the energy consumption of their houses and foreseen with a reasonable accuracy the energy consumption of livestock housing as regards the ventilation, heating and cooling, that for some intensive rearing systems represent the major energy uses.

The energy audit of livestock houses and the possible energy retrofitting are subject to a preliminary benchmarking activity with the aim of comparing the measured performance with reference data. In this paper, a review of values of energy use for the climate control (ventilation, heating, lighting and cooling) of livestock houses that can be taken as a reference are presented for some European countries. This work will be useful to develop reference values in order to compare measurements and numerical simulations and to identify different livestock housing systems as a function of the energy use and environmental performance of the houses.

Animal production has strongly incremented its production since the '60s, and this trend is going to be the same in the further coming future at least until the half of this century, when, for example, an increment of about 70% in meat consumption is estimated [3]. Simultaneously, the importance of the energy use in this sector is increasing too, due to the application of new technologies and the continuous rise of energy sources prices [4].

The target of this paper is to retrieve and compare some energy use values found in literature of different European countries related to some of the most common animal productions. For the analysis, only heating, cooling, ventilation and lighting energy uses were considered, as energy uses related to the control of the indoor environment of the enclosure.

2. Literature sources and methods

2.1. Literature sources

The entire work is based on a bibliographical review. The documents were consulted with the aim to find energy values useful for proposing energy use values.

The investigation started from the reference document at European level in this field (Best Available Techniques-BAT)" [5], where the best solution concerning poultry and swine breeding are reported. Its goal is to disseminate and promote the best techniques and technologies available as regard for example odors' emissions, treatment of waste, noise problems and consumption of water and energy. In this document, many data are present, but very few were useful for the energy use analysis, because most of them regard other production issues too.

The most interesting document for obtaining energy use values was "Progetto Re Sole" [6]. It focuses on broilers (chickens reared for meat production), laying hens (egg production), swine and dairy cows, referring to Emilia-Romagna, an Italian region with a high concentrations of livestock houses. This project was carried out by a research institute and started in 2009, ending in 2013, with the final aim to promote the use of energy saving systems, especially solar thermal and photovoltaic collectors. In order to do that, the different uses of energy in various types of animal farms were investigated through a sample and an analytical analysis. The first one consisted in sending questionnaires to farms that filled out them with their data, while the latter one consisted in direct measurements carried out by the researchers. Data are divided by final use (e.g. ventilation, feeding) and type of energy (thermal or electrical) and reported to livestock unit (LSU), a unit of measurement that facilitates the comparison of environmental impact or feeding requirements between different species of livestock. The final results are average values. A similar report was done also by the Swedish University of Agricultural Sciences [7]. In that case the production data are also presented.

Reports from other countries are also used, for example, those coming from France, written by institutions as ITAVI (a French research institute) and ADEME (French agency for energy and environment) and they refer to specific regions of that country, as Loire or Brittany [8, 9, 10]. These reports only regard poultry, focusing on many different species as broilers, laying hens or minor productions, as ducks. In the last section of some of these reports, there are charts for allowing the farmers to calculate their own energy consumptions in order to compare them with some provided benchmarks of electricity and gas consumption.

Others data come from conference proceedings [11, 12] and in many cases they have also a market driven tendency. In [11] for example, simulations in order to analyze all the financial costs of different typologies of similar livestock houses for individuating the breakeven selling prices of the meat are performed. Knowing or estimating the energy costs, it is possible to discover the energy consumption data. Some other data were found, but they were not used because they considered all the different energy uses (e.g. heating, milking) in a single value or do not distinguish thermal energy from electrical one.

In order to understand the differences among the presented data it is necessary to considerate the climate and the normal practices of the various analyzed countries. Data came from various analysis and reports with different aims and for this reason they are expressed referring to different units of measurement. For example, in most cases the energy (expressed in kWh or Wh) is referred to the considered animal, but sometimes also to the breeding place, to the livestock unit (LSU), to the carcass or to the unit of product (e.g. kg of meat).

In order to obtain comparable results, a common unit of measurement was necessary. For this reason, all the results were expressed in kWh/m^{2}year according to the engineering nature or this work and because these values may be the basis for an energy certification scheme similar to the one used for other building types (e.g. residential, offices). A second value expressed in Wh/unit of product was given because the obtained data may be also the basis for other studies based on a LCA perspective. For having the same unit of measurement in all the values, the following assumptions regarding the animal productions were made.

2.2. Breeding assumptions

In Europe different species of animals are bred with different purposes and in different manners. In this paper, the most important animal breeding types are analyzed, considering these rearing types that highly use energy for heating, cooling, ventilation and lighting.

For the meat production sector, pigs and chickens rearing was analyzed. Broiler (chickens for meat) production starts with chicks of few days carried at the broiler house where they stay for 40 to 70 days for reaching the slaughter weight, about 1.6 kg of live weight. Once this cycle (called "batch") is ended, there is a week for restoring the hygienic conditions required by normative and then other chicks are carried to the farm for restarting a batch.

Pig breeding is more complex than broiler rearing, because a pig's production cycle has more stages than broilers, and lasts between 25 and 39 weeks. Swine could be reared with a closed or an open system; the main difference between these two types is that in the first one all the swine's life stages take place in the same pig unit, while in the second one the animals (usually weaned pigs) are moved to another farm for the growing and finishing periods, till the slaughter weight. Usually pigs are slaughtered when they weigh between 90-110 kg (butcher's meat production) or 150-170 kg (dry-cured ham).

Table 1. Assumptions for meat production (broilers and pigs).

Parameter	Broilers	Pigs		Unit of measurement
		Open cycle system	Closed cycle system	
Stocking density	17	1.41	1.31	Animals/m^2
Number of batches	7	/	/	Batches/year
Live weight	2.2	150	150	kg/animal
Carcass yield	73	80	80	%
Carcass weight	1.6	120	120	kg/animal
Production	190.40	215.71*	311.40*	kg$_{meat}$/m^{2}year

*The meat production is not calculated on the basis of the density, but on the slaughter weighted pigs produced for each year. In particular, there are 286 pigs for open cycle system (on 159.1 m^2 of area) and 209 pigs (on 80.54 m^2 of area) for closed cycle system.

Laying hen production is analyzed, due to the importance of egg production in EU [13]. These animals could be reared in different ways, but in this text only enriched cages and free range system are considered. The difference between the two types of rearing is the animal stocking density that is considerably higher in enriched cage system (each hen has 750 cm^2 of free space [14]). Table 2 show the rearing assumptions for laying hens. It is important to highlight that egg production could vary a lot depending on the species considered and on the farm management.

Table 2. Assumptions for egg production (laying hens).

Parameter	Laying hens		Unit of measurement
	Free range system	Enriched cages system	
Stocking density	6	16	Animals/m^2
Production*	1998	5328	Eggs/m^2year

*A production of 20 kg_{eggs}/hen·year is considered (equal to 333 eggs/hen·year).

The aim of this paper was also to analyze the dairy cow rearing for milk production, but very few data are present in literature. For this reason, the work considers dairy cows analyzing only the energy share consumption, without giving energy use values. Therefore, no assumptions were made for this breeding.

The last assumption concerns the livestock unit (LSU), for which the Authors referred to the European Commission Regulation 1200/2009 [15] regarding the livestock unit coefficients.

3. Results

3.1. Energy uses in livestock houses

In this paragraph, data on the global energy consumption are given. Even though the aim of this work is to show energy values related to the indoor environmental control, it is also important to understand how much these values account in the total energy consumption.

As showed in Table 3, broiler, laying hen and pig rearing have similar energy uses and they are related to the environmental control (heating, cooling, ventilation and lighting), to feeding (preparation and distribution of feed), to manure management (treatment, transportation, disposal of manure and litter care) and finally to the product manufacturing.

In a broiler house, as showed in Table 3, the environmental control accounts for 75.5% of total electrical energy and 96.3% of thermal energy, being the biggest macro-category of energy use. Ventilation and cooling (obtained by wind chill effect) consume the biggest amount of electrical energy (39.5%), followed by electrical heating (26.9%); almost all thermal energy is consumed fory heating.

In laying hen houses, the electrical energy for indoor environmental control is 58.9%, while no thermal energy is needed in this production type. Ventilation and cooling need 43.7% of electrical energy, while only a minor amount is needed for lighting.

In swine production, 50.2% of electrical energy consumed is needed for environmental control, in particular 47.7 is needed for ventilation and localized heating (for the piglets) and 2.5% for lighting; the thermal energy consumption is 69.2% of the total and all is needed for general heating.

Table 3. Percentages of energy consumption for broilers, laying hens (referred at single place) and pigs (referred at LSU) [6].

Operation	Broilers		Laying hens		Pigs[1]	
	Electrical energy	Thermal energy	Electrical energy	Thermal energy	Electrical energy	Thermal energy
Ventilation and cooling[2]	39.5%	0	43.7%	0%	/	/
Ventilation and heating[3]	/	/	/	/	47.7%	69.2%
Heating	26.9%	96.3%	0	0%	/	/
Lighting	9.1%	0	15.2%	0%	2.5%	0%
Feeding distribution	19.8%	0	5.4%	0%	18.7%	0%

Feeding preparation	/	/	/	/	11.3%	0%
Litter care and manure removal	0%	2.8%	2.2%	33.3%	3.8%	1.3%
Manure treatment	/	/	26.7%	0	3.7%	0%
Manure transportation and disposal	0%	0.9%	0%	66.7%	12.3%	29.5%
Product collecting and package	4.7%	0%	6.8%	0%	/	/
TOTAL	100%	100%	100%	100%	100%	100%
Whereof for environmental control	*75.5%*	*96.3%*	*58.9%*	*0%*	*50.2%*	*69.2%*

"/" means that specific task is not carried out in the connected livestock type, [1]The data refer to a mean of open and closed cycle systems, [2]Cooling is considered obtained through wind chill effect of ventilation, [3]Electrical heating (e.g. electric lamps) is for piglets, thermal one (e.g. gas heaters) is general heating.

Data concerning dairy cows breeding are reported in a different table (Table 4) because in this type of rearing, milking tasks (so tasks directly connected the final product production) have an important role. In broiler and pig houses the main activities connected to the final product (meat) are carried out in other buildings; in egg production the energy used for collecting and, eventually, packaging the eggs is only a little percentage of the total (6.8% of electrical energy). In dairy production, milking and milk cooling consume respectively 16.3% and 12.0% of total electrical energy (a total of 28.3%) and 6.4% of thermal energy (due to milking), as showed in Table 4.

Table 4. Percentages of energy consumption for dairy cows (referred at LSU) [6].

Operation	Electrical energy	Thermal energy
Ventilation	20.0	0
Lighting	7.4	0
Feeding	17.0	51.9
Milking	16.3%	6.4%
Milk cooling	12.0%	0%
Litter care and manure removal	8.1%	11.7%
Manure treatment	18.2%	4.1%
Manure transportation and disposal	1.0%	25.9%
TOTAL	100%	100%
Whereof for environmental control	*27.4%*	*0%*

3.2. Energy uses for climate control

Here the energy consumption values found in the literature are presented; these values were used for formulating the ranges presented later.

Table 5 and Table 6 show values for broilers. Due to the high number of values, some considerations had to be done in order to do consider only reliable data for calculating the energy use reference values, for example the heating data coming from Finland that are very high due to the climate conditions. The value of 197 kWh/m^{2}year is not considered representative because it refers to a simple broiler houses with no thermal insulation and low technology [11], so it is a particular situation. Other data that are not considered are the ones for lighting: they are few and some of them (the Spanish ones) have not reliable ranges. For this reason, an energy use value for lighting in broiler house is not given. For calculating the energy use values, data of total electrical energy present in Table 6 that included all the electrical uses (e.g. feeding, litter care) are not considered.

Table 5. Energy consumption values for end use for broiler production.

Source	Country	Heating		Ventilation		Lighting	
		kWh/m^2year	Wh/kg_{meat}	kWh/m^2year	Wh/kg_{meat}	kWh/m^2year	Wh/kg_{meat}
[9]	France	93.80	380.00	7.31	29.76	4.94	19.86
[8]	France	86.00	440.00	NA	NA	NA	NA
[10]	France	103.10	420.00	7.81	41.00	5.28	27.70
[11]	Spain	197.00	1515.15	6.05	46.30	0.94	7.18
[11]	Spain	137.48	757.58	8.40	46.30	0.59	3.27
[11]	Spain	104.93	454.55	10.69	46.30	0.50	2.17
[16]	Italy	102.38	390.00	0.75	3.90	NA	NA
[6]	Italy	4.28_e 113.54_t	22.00_e 596.30_t	6.29	33.00	1.45	7.58
[7]	Sweden	91.63	481.25	3.97	20.80	11.65	61.19
[17]	Sweden	112.56	591.10	NA	NA	NA	NA
[5]	Finland	243.00	1558.00	NA	NA	NA	NA
[17]	Finland	213.54	1121.57	NA	NA	NA	NA
[5]	UK	130.90	687.50	NA	NA	NA	NA

NA= Not Available, e= electrical, t= thermal

Table 6. Total electrical and thermal energy consumption of broiler houses.

Source	Country	Total thermal energy		Total electrical energy		Notes
		kWh/m^2year	Wh/kg_{meat}	kWh/m^2year	Wh/kg_{meat}	
[9]	France	93.80	380.00	12.25	49.62	/
[8]	France	86.00	440.00	NA	NA	/
[10]	France	103.10	420.00	13.09	68.70	/
[11]	Spain	197.00	1515.15	6.99	53.48	*Simulated data
[11]	Spain	137.48	757.58	8.99	49.57	*Simulated data
[11]	Spain	104.93	454.55	11.19	48.47	*Simulated data
[16]	Italy	102.38	390.00	0.75*	3.90*	*Lighting values are not present
[6]	Italy	113.54	596.00	12.02	62.58	/
[7]	Sweden	91.63	481.25	15.62	81.99	/
[17]	Sweden	112.56	591.10	19.30*	101.38*	*Including all the electrical uses
[5]	Finland	243.00	1558.00	14.28*	91.54*	*Including all the electrical uses
[17]	Finland	213.54	1121.57	30.97*	162.67*	*Including all the electrical uses
[5]	UK	130.90	687.50	65.45*	340.00*	*Including all the electrical uses

NA= Not Available.

In Table 7, data regarding laying hens are presented and is it possible to notice that free range farms generally need a minor amount of energy per square meter if compared to enriched cage system. That depends on the different densities: a lower number of hens for square meter implies less energy needed for maintaining air temperature and humidity, but, on the other hand, it means a littler egg production. In particular, the highest total energy consumption value comes from a cage rearing system (50.40 kWh/m^{2}year) while the lowest one from a free range farm (14.70 kWh/m^{2}year).

Table 7. Energy consumption values distinguished by use in laying hen production.

Source	Country	Ventilation		Lighting		Total electric energy	
		kWh/m^{2}year	Wh/egg	kWh/m^{2}year	Wh/egg	kWh/m^{2}year	Wh/egg
[6]	Italy[1]	15.42	3.86	5.38	1.35	20.80	5.20
[9]	France[2]	NA	NA	NA	NA	50.40	9.46
[9]	France[3]	NA	NA	NA	NA	14.70	7.36
[7]	Sweden[2]	20.00	3.75	23.26	4.37	43.23	8.12
[7]	Sweden[3]	12.93	6.47	14.59	7.30	27.52	13.77

NA= Not Available, [1]Average between 3 enriched cages farms and 2 free range farms, [2]Enriched cages farms, [3]Free range farms.

Data in Table 8 show the values for pig rearing, focusing also on the different stages of their life. From the data it is possible to understand that the highest values for ventilation and localized heating come from the closed cycle system, because piglets (that are present in this type of farms) need more heating, while in the open cycle system there are only growers and fattening pigs. Lighting values have an opposite trend, because older pigs need more light than younger ones (it is possible to confirm it looking the lighting energy use values at the different life stages).

Generally, farms that use open cycle system are more convenient from an energy point of view, but from a financial point of view the surplus costs of closed cycle system are amortized when piglets are sold to the other farms.

Table 8. Energy consumption values distinguished by use in pig production.

Source	Country	Ventilation and localized heating		Lighting		Total electric energy	
		kWh/m^{2}year	Wh/kg$_{meat}$	kWh/m^{2}year	Wh/kg$_{meat}$	kWh/m^{2}year	Wh/kg$_{meat}$
[6]	Italy[1]	37.08	119.22	1.11	3.57	38.19	122.79
[6]	Italy[2,3]	37.45	173.61	2.85	13.21	40.30	186.82
[5]	UK[3]	33.58	155.65	5.45	25.29	39.03	180.94
Grower[4]		23.18	107.45	4.43	20.56	27.61	128.01
Weaner[4]		8.93	41.38	0.90	4.17	9.83	45.55
Piglet[4]		1.47	6.82	0.12	0.56	1.59	7.38

[1]Open cycle system, [2]The data presents also general heating with 31.17 kWh/m^2 or 144.44 Wh/kg$_{meat}$. [3]Closed cycle system, [4]Separated data of BAT (2015) divided for life stages (the data of each life stage refer to a slaughter weight of 150 kg).

3.3. Reference energy uses for climate control

In Table 9 a reliable range of energy uses values is given for each breeding type. It is possible to notice that the ranges are quite large, in fact the ratio between the maximum and the minimum values goes from approximately 1 (for the total electrical energy expressed in kWh/m^{2}year in pig production), to 7 (e.g. lighting in laying hens). All the lighting energy use values have a considerable difference between maximum and minimum values (ratios of 4.6, 7, 5 and 6.25 following the Table 9 order), while all the other ranges have a ratio between 1.05 (total electrical energy for pigs) and 2.75 (ventilation for broilers). Therefore, this means that lighting energy use values are more variable than the others and a big uncertainty concerns this electrical use is observed. Range values are very different between them due to the different technologies used and the various climates.

Table 9. Ranges of energy use values.

Operation	Broilers		Laying hens		Pigs	
	kWh/m^{2}year	Wh/kg$_{meat}$	kWh/m^{2}year	Wh/egg	kWh/m^{2}year	Wh/kg$_{meat}$
Heating	86-137	380-758	0	0	NA	NA

Ventilation	4-11	21-46	15-20	4-6	/	/
Ventilation and local heating	/	/	/	/	34-37	119-174
Lighting	NA	NA	5-23	1-7	1-5	4-25
Total electrical energy	7-16	48-81	43-50[a]	8-9[a]	38-40	123-187
			15-25[b]	7-14[b]		
Total thermal energy	86-137	380-758	0	0	NA	NA

[a]Enriched cage rearing system, [b]Free range rearing system, NA= Not Available, "/"= Use not present for that rearing type.

4. Conclusions

The results obtained in this paper are a first step in a project for the assessment of the energy use for the climate control of animal houses. A further development may be to formulate energy classes (as in the certification scheme for buildings) that allow comparing an existing or designed animal house energy performance to the energy performance of a reference one. The values reported in this paper comes from the few data available into bibliographical sources issued from different projects (measurements, simulations, etc.) developed in various European countries. The review showed that the energy use for climate control is large in broiler houses and that only pig and broiler houses present a significant quantity of thermal energy use for climate control. In order to refine the reliability of the data and to increase the number of observations, this work may be implemented with new dedicated research activities through questionnaires, real measurements and simulations on reference case studies.

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References

[1] European Council. Laying down minimum rules for the protection of chickens kept for meat production, Dir. 2007/43/CE. 28th June 2007.
[2] European Council. Laying down minimum standards for the protection of pigs, Directive 2008/120/EC. 18th December 2008.
[3] FAO. World Livestock 2011 – Livestock in food security. Rome: FAO; 2011.
[4] Fabrizio E, Ghiggini A, Bariani M. Energy performance and indoor environmental control of animal houses: a modelling tool. Energy Procedia, vol. 82, 439-444; 2015.
[5] European Commission. Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs. Seville: IPPC Bureau; 2015.
[6] Rossi P, Gastaldo A, Riva G, de Carolis C. Progetto Re Sole (bozza finale). Reggio Emilia: Centro Ricerche Produzioni Animali; 2013.
[7] Hörndahl T. Eenergy Use in Farm Buildings – A study of 16 farms with different enterprises. Revised and traslated second edition. Alnarp: Swedish University of Agricultural Sciences, Faculty of Landscape Planning, Horticulture and Agricultural Science; 2008.
[8] ADEME. Les consommations d'énergie en bâtiments avicoles - Années de références 2006 et 2007 – Bourgogne. S.l.: ADEME; 2010.
[9] Amand G, Bonnouvrier A, Chevalier D, Dezat E, Nicolas C, Ponchant P. Les consommations d'énergie en bâtiments avicoles. Noyal-sur-Vilaine, Rennes: ITAVI, ADEME; 2008.
[10] ITAVI. Synthèse des consommations de propane et d'électricité en aviculture. S.l.: ITAVI; 2010.
[11] Arellano Peche G. Evolución y situación actual de los costes de producción en las granjas de broilers. In "Jornadas profesionales de avicultura". Pamplona; May 3rd-7th 2010.
[12] Oviedo Rondón EO. Ahorro energético en granjas avícolas. In "XLVI Symposium científico de avicultura.". Zaragoza; October 29th- November 2nd 2009.
[13] Committee for the Common Organisation of the Agricultural Markets. EU Market Situation for Eggs. Available at: <https://circabc.europa.eu/sd/d/18f7766e-e9a9-46a4-bbec-94d4c181183f/0%20Circa%20%20egg%20no%20links.pdf>, (Accessed on April 21st, 2016).
[14] European Council. Laying down minimum standards for the protection of laying hens, Directive 1997/74/EC. 19th July 1999.
[15] Commission Regulation (EC). Implementing Regulation (EC) No 1166/2008 of the European Parliament and of the Council on farm structure surveys and the survey on agricultural production methods, as regards livestock unit coefficients and definitions of the characteristics, Dir. 1200/2009. 30th November 2009.
[16] Blázquez D, Del Olmo M. Manual de eficiencia energética para PYMES. Avicultura (granjas avícolas). Spain: Gas Natural Fenosa; 2008.
[17] Rajaniemi M, Ahokas J. Direct energy consumption and CO2 emissions in a Finnish broiler house – a case study. Agricultural and Food science 24, 10-23; 2015.