Heating and cooling load analysis of a climate neutral proof of concept chicken farm

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Abstract:

In this work, a proof of concept design for a poultry meat farm is studied. The design aims to be climate-neutral and energy-flexible by applying different technologies such as PV panels, PVT panels, BEO field, and high and low-temperature heat pumps. In order to size these systems, the farm's required heating, cooling power and (de)humidification rate has to be estimated, which is the focus of the current paper. For this purpose, a model was created in the Python environment. Based on the building's current design, expected weather conditions throughout a model year, and the required conditions for the chickens' well-being, the heating and cooling loads are calculated. The analysis does not yet take into account which technology is used to supply the heat as the sizing will be done based on the results of this analysis. In addition to the 'standard' climate requirements, some pens will be used to study the behaviour of the chickens during alterations in the temperature and humidity of the pen. These tests are predefined and the HVAC installation should be able to handle these test conditions as well. The results of the model can be used as a guideline to size the different HVAC systems. However, as the model is based on assumptions and simplifications, a sensitivity analysis was performed as well. This analysis shows that the conductive losses are small compared to ventilation and infiltration losses. The air changes per hour of the farm have a great impact on the total required heating and cooling power. Therefore, attention should be given to the air-tightness of the chicken pens to reduce the required installation size.

Keywords:

Energy-use; Poultry farm; Energy neutral; model.

1. Introduction

The sustainable development goals, adopted by the United Nations, are a set of 17 interconnected goals aimed at addressing global challenges such as poverty, hunger, inequality, and climate change. The second goal, "Zero Hunger," recognizes the need for sustainable agriculture to provide adequate food for a growing population while reducing the negative environmental impact of current agricultural practices.

Sustainable agriculture aims to achieve food security and enhance livelihoods while conserving natural resources and minimizing negative effects on the environment. To achieve this, it is essential to adopt low-carbon technologies in agriculture to reduce greenhouse gas emissions, improve resource-use efficiency, and promote biodiversity. Poultry farming, which is a vital component of the agricultural sector, has a significant role to play in achieving sustainable food production.

The ever-increasing demand for poultry products [1] due to the relatively low climate impact compared to other meat variants has put pressure on farmers to increase production. However, this increase in production must be achieved using renewable methods that minimize environmental impact. In this context, several studies [2-6] have been conducted to explore low-carbon technologies that can be implemented in the poultry farming industry to reduce greenhouse gas emissions and promote sustainable practices. However, not all technologies can be applied in all regions or for all power requirements.

Therefore, this study seeks to contribute to the development of sustainable poultry farming by focusing on a methodology to predict the required heating and cooling demand of a new poultry farm design. This methodology is essential to ensure that the heating and cooling systems used on the farm are appropriately sized, leading to energy efficiency and a reduction in greenhouse gas emissions. The findings of this study

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can help farmers and policymakers make informed decisions about the design and implementation of sustainable heating and cooling systems in poultry farming which are currently not often used within this sector, ultimately contributing to achieving the second sustainable development goal of the United Nations.

Information on the dimensions and requirements for the poultry farm were provided by ILVO, a Flemish research centre [7]. This farm will be used to conduct detailed research with respect to a plethora of factors, ranging from feed composition, feed management, and animal well-being to emissions, impact of climate control, and energy flexibility of the stable depending on electrical grid conditions.

2. Modelling methodology

2.1. Standard boundary conditions

A new poultry farm has been designed to house up to 14,000 chickens. The goal is to construct this new farm in an energy-flexible and climate-neutral manner as a proof-of-concept. To achieve this, the required heating, cooling, humidification, dehumidification, and ventilation rate has to be estimated based on the required optimum conditions for the chickens and the outside weather conditions. The design temperatures and humidities are presented in Table 1 based on the age of the chickens within the pen expressed in days. On the days not mentioned in Table 1, the values are obtained by interpolating between the two adjacent values.

Table 1. Climate set point and minimum ventilation rate within the stable depending on the age of the chickens.

Chicken age (days)	Average weight (g)	Temperature (°C)	Relative humidity (%)	Minimum ventilation rate (m³/kg/h)
0	45	34	55	1.5
3	90	34	55	1.4
7	180	31	60	1.3
14	470	27	70	1.1
21	920	25	70	0.9
28	1480	22	70	0.8
35	2110	22	75	0.7
42	2770	21	75	0.7

Another important input characteristic to the developed model (see section 2.4) is the heat and humidity produced by the chickens themselves. The following equations, in function of the average chicken weight, are used for this:

$$Q_{chicken} = 10.62 \cdot m_{chicken}^{0.75}, \tag{1}$$

$$m_{vapour,chicken} = -17.7 \cdot m_{chicken}^{2} + 200 \cdot m_{chicken} + 22, \tag{2}$$

where $Q_{chicken}$ is the heat produced per chicken in watt, $m_{chicken}$ is the average mass of a chicken (at a certain age) in kilogram and $m_{vapour,chicken}$ is the amount of grams of water vapour produced by a chicken in a day.

The ventilation rate which can or should be applied in the farm has prescribed minimum and maximum values. The minimum ventilation rate depends on the chickens' weight and is also represented in Table 1. The maximum ventilation rate is 4 m³/kg chicken/h. This norm is quite high compared to other animals due to the high heat production of poultry. A second limitation to take into account is that the ventilation rate should always be sufficient to keep the carbon dioxide concentration beneath 3000 ppm. As the prescribed minimum ventilation rate already is always higher than the ventilation rate posed by this limitation, the carbon dioxide concentration is not taken further into account. The actual applied ventilation depends on the applied climate control. The climate control considered in this work is based on temperature solely and is illustrated in the next graph. It should be noted that this strategy holds when the outside temperature is lower than the temperature inside the pens. The target temperature (TT) inside the pen is allowed to vary between a certain range (defined by T0 and T1) without applying external measures. When the temperature drops below T0, which is already at a minimum ventilation rate, the heating system is turned on. When the temperature increases beyond T1, the temperature is controlled by increasing the ventilation rate. At a certain point (at T2), the temperature cannot be reduced enough by solely increasing ventilation flow rate. When the temperature exceeds T3, active cooling is applied to lower the temperature inside the pens.

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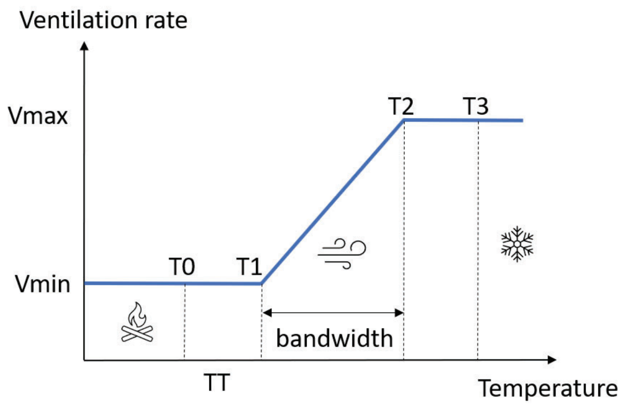

Figure 1.: Applied climate control in poultry farm.

2.2. Special boundary conditions for heat and cold stress tests

The temperatures and relative humidities from Table 1 represent the requirements for the chickens under ‘standard’ stable conditions. However, sometimes, extreme conditions have to be applied to the pens in order to create a ‘stressful’ environment for the chickens. This way, the researchers of ILVO can perform heat and cold stress tests and investigate the influence of these conditions on the chickens. The conditions for the heat stress tests are as follows (in function of the age of the chickens):

- Day 3-6: 24h at 40°C and RH 65%
- Day 7-25: 12h/day at 39.5°C and RH 65%
- From day 26: 8h/day at 36°C and RH 70%

The conditions for the cold stress tests are:

- Day 1-6: 24h at 24°C and RH 40-50%
- Day 7-13: 24h at 15°C and RH 40-50%
- Day 14: 24h at 13°C and RH 40-50%
- Day 15-26: 24h at 13°C and RH 50-55%

These conditions only have to be applied in 3 (adjacent) compartments of the 9 compartments, and have to be reached within 2 hours. Also, the return to standard conditions has to happen within 2 hours. 720 chickens are present in all 9 compartments. While 3 compartments are put under the stress test conditions, the other six compartments follow the standard conditions mentioned in section 2.1.

2.3. Layout of chicken farm

Table 2. Thermal resistances.

Type and location	Value [m²K/W]
Convection external side wall	0.02
Convection internal side wall	0.25
Convection floor	0.25
Convection ceiling	0.25
Conduction external wall between compartment and outside	7.77
Conduction internal wall between compartments	2.62
Conduction internal wall between compartment and air lock	2.52
Conduction internal wall between compartment and food compartment	2.52
Conduction internal wall between food compartments	2.43
Conduction external wall between food compartment and outside	1
Conduction ceiling	4
Conduction floor	4.17
Conduction roof	3.2

In addition to the required climate, the dimensions and layout of the modeled stable also have an important impact on the final results. The stable is divided into 9 compartments, which can each contain up to 1555 chickens. Three compartments make up one department, with each their own air conditioning unit. Next to these compartments, food compartments are located which separate the chicken compartments from the outer walls. Additionally, an attic is located above the chicken compartments. The design has predefined interior wall, exterior wall, floor, and ceiling construction materials and thicknesses which are used in the model to calculate conductive thermal resistances between two adjacent areas. The convective thermal resistances are calculated with constant convection coefficients, which are taken conservatively based on the default values of TRNSYS 16 TRNBuild [8]. The thermal resistances are listed in Table 2 and a sketch of the compartment layout is illustrated in Figure 2.

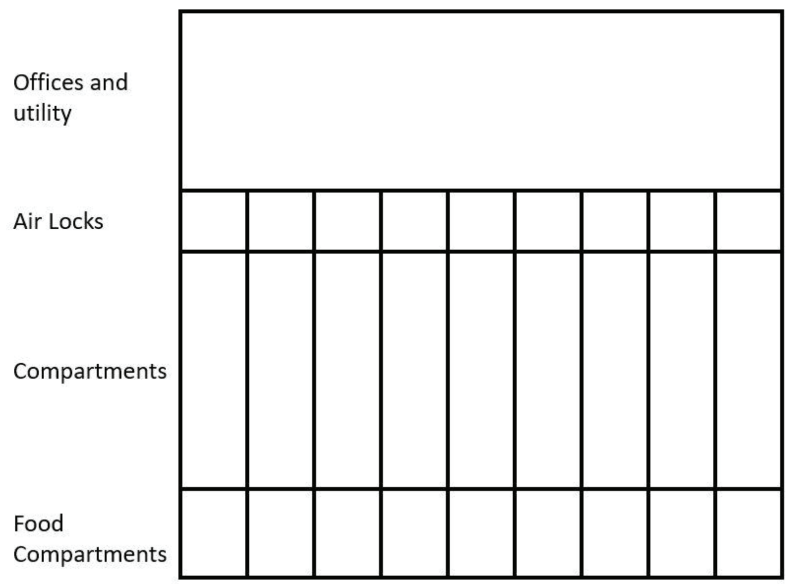

Figure 2. Sketch of the layout of the poultry farm consisting of nine air-locks, chicken compartments, and food compartments as well as a room for offices and utility.

2.4. Model strategy

For the modelling, which was done in Python 3.7 [9], the poultry farm was divided into 19 zones: 9 chicken compartments, 9 food compartments and the attic. For each zone, three balances were calculated: an energy balance, a mass balance (w.r.t. the air supply) and a moisture balance. In the zones containing chickens, the heat and vapour production by the chickens was taken into account, as well as the heat conduction to adjacent chicken zones, food compartment, attic, air-lock, ground and outdoors. In addition, direct solar gains due to six installed Solatubes [10] per chicken compartment, were also added. Lastly, the contribution of the heat and vapour transferred through ventilation and infiltration of air was included. For the food compartments, the conduction is similar to the chicken compartments. However, there are no internal (heat or vapour) gains, no ventilation and no Solatubes. When simulating the attic, only conduction to chicken compartments and the outdoor environment is taken into account.

For simplicity, the infiltration losses are taken into account by assuming a constant infiltration rate in the model. This is expressed by certain ‘air changes per hour (ACH)’. It is assumed the fresh air in the chicken compartments is coming from the food compartments. This same infiltration rate, in its turn, is coming through cracks and crevices from the outside environment. As a default, 1 ACH is taken, and the influence from this assumption is evaluated later on.

Two ventilation strategies are considered, which influence the energy balance. The first one dictates that the target temperature and humidity inside the chicken compartments are always maintained. In this strategy, the ventilation rate is put to the minimum value, and additional heating or cooling is applied to reach the target temperature. In the second strategy, the control depicted in Figure 1 is applied. Here, different temperatures than the target temperature are allowed (within a certain range) before heating or cooling is needed. This will have a significant impact on the required heating and cooling load. In the model, this problem is solved iteratively by searching for the temperature and ventilation rate combination where the required (sensible) load is minimal. As a default, the minimum ventilation strategy is applied. In section 3.4.2, the influence of applying the second strategy is discussed.

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The heat losses to the air-lock are dependent on the temperature of the air-lock, which is unknown. Therefore, this temperature was assumed to be at the average temperature of the compartments and outdoors, with a minimum of 18°C. As the attic and food compartments do not have a target temperature, the temperature in these compartments is solved iteratively based on reaching an energy balance between the heat losses and the heat gains. In addition, a minimum temperature of 18°C is set in the food compartments.

3. Simulation results with fixed outdoor conditions

3.1. Steady-state cooling and heating loss calculations

In the calculations presented in this section, the outdoor temperature is fixed at certain values, varying from -10°C to 35°C. The outdoor relative humidity is fixed at 50%. The heating and cooling loads were calculated for different chicken occupations (both in age and number). 1555 chickens per compartment represents the maximum capacity of the farm, 720 chickens per compartment represents the standard occupation. Table 3 gives an overview of the sensible loads, expressed in kW, for the entire poultry farm. Positive values indicate heating, negative values indicate cooling. For standard occupation conditions, the maximum sensible heating load is thus 141 kW, the maximum cooling load is 157 kW.

Table 3. Heating and cooling loads (sensible) (in kW). RH (outside) = 50%.

		Number of chickens per compartment	
Outdoor temperature (°C)	Age (d)	720	1555
-10	0	107	113
	14	111	136
	28	120	168
	42	141	216
0	0	81	86
	14	75	88
	28	70	89
	42	74	101
10	0	55	58
	14	39	40
	28	19	16
	42	17	-30
20	0	30	31
	14	4	-8
	28	-31	-71
	42	-59	-128
30	0	7	7
	14	-29	-54
	28	-79	-149
	42	-124	-242
35	0	-5	-6
	14	-46	-77
	28	-104	-188
	42	-157	-299

The highest heating load corresponds to older chickens, however, this is strongly dependent on the outdoor conditions as well. In addition, the higher the number of chickens in a compartment, the higher the load. This finding is a result of the allowed ventilation rate and the chickens own heat production. The load for one department (so three compartments) is, by approximation, equal to 1/3rd of the total load. In reality, the demand of compartments located near the outdoor environment will be different to the ones more in the center, due to the heat losses to the environment.

3.2. Analysis of the energy balance

In this section, the results from section 3.1 are investigated in more detail by zooming in on the energy balance. In particular, identifying the dominant heat losses allows for reducing these by adjusting the farm design. The results presented in this section are based on the simulations for a stable with 720 chickens per compartment at an age of 42 days, as this age resulted in the highest cooling and heating loads according to section 3.1. The trends observed are however also applicable to the other occupation combinations. In Figure 3, the energy balance in winter (i.e. -10°C outside) for the entire stable is depicted, divided into energy input (left) and energy output (right). The input contains the heat production of the chickens, the heat gains because of the Solatubes and the required heating. The output contains the ventilation and infiltration losses (to the air-locks) and the conduction losses.

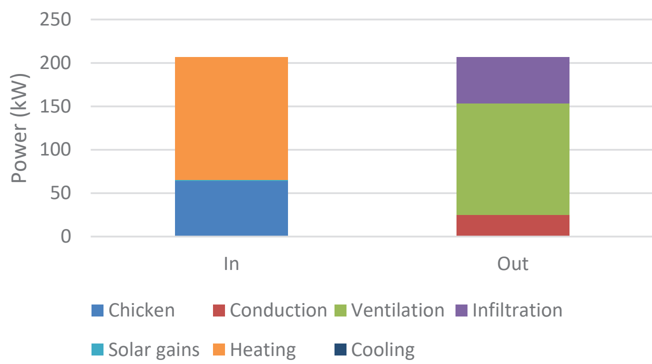

Figure 3. Energy balance (sensible) in winter (-10°C) for entire stable (720 chickens/compartment at 42 days old). RH (outside) = 50%.

Based on this figure, it can be concluded that the Solatubes mainly serve as light source, but do not really contribute to the heat balance. It should be noted that the impact of the incident solar radiation on the remainder of the roof and outer walls is not taken into account in the calculations, as the impact will be limited. The expectation is that when incorporating these, the conduction losses through the attic and outer walls will likely decrease, as they will be at a higher temperature than considered in the current simulations.

The conduction losses are also small compared to the ventilation and infiltration losses. The ventilation rate accounts for 62% of the total losses. This is the largest component for the oldest chickens, which is also likely the reason why the maxima occur for these ages as seen in Table 3. Therefore, if technically possible, the required heating load could be strongly reduced by incorporating an energy recuperation system on the ventilated air.

The conduction losses from Figure 3 are split up into each heat loss stream in Figure 4. The largest share of conduction losses is through the ground. This might be the result of some assumptions and simplifications that were made, as the ground is a difficult part to model due to the influence of floor heating and additional insulation. However, as the overall influence of conduction losses on the total heat balance is limited, it is expected that the applied model for the ground does not have a significant influence on the main results.

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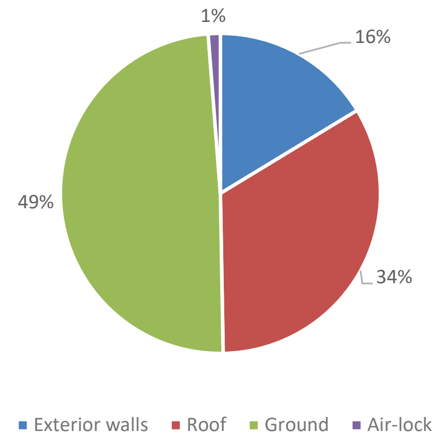

Figure 4. Distribution of conduction losses (sensible) in winter (-10°C) for entire stable (720 chickens/compartment at 42 days old). RH (outside) = 50%.

A similar analysis as described above was made for conditions during summer (i.e. 30°C outside). The results for the energy balance are given in Figure 5. The heat gains due to the Solatubes and the heat generation of the chickens are still the inputs. However, under these conditions, the ventilation, infiltration and conductive heat streams are also inputs as the outside temperature is higher than the target temperature. The largest share is the heat produced by the chickens themselves, ventilation is the second largest share. The only energy output is the cooling load.

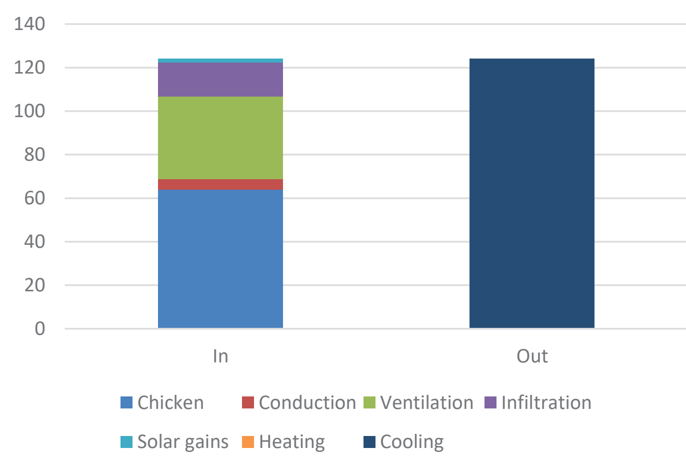

Figure 5. Energy balance (sensible) in summer (30°C) for entire stable (720 chickens/compartment at 42 days old). RH (outside) = 50%.

3.3. Required loads during stress testing

3.3.1. Heat stress tests

The heating loads for the three compartments put under the heat stress test conditions (as described in section 2.2) are illustrated in Figure 6. The heating loads are expressed in function of the age of the chickens and the outdoor temperature. The gap at day 25 is due to the change in setpoint condition as mentioned in section 2.2. As expected, the highest heating loads correspond to the lowest outdoor temperatures. For an outdoor temperature of 30°C or 35°C, no heating is required when the chickens are older (negative values in the graph). In these cases, there is cooling required, although reduced compared to the standard conditions. The maximum requirement for a heat stress test at 0°C outside temperature does not exceed the required heating power of one department at -10°C which is 47 kW. This is 1/3rd of 141 kW as can be seen in Table 3 for 720 chickens per compartment. So no additional capacity has to be installed.

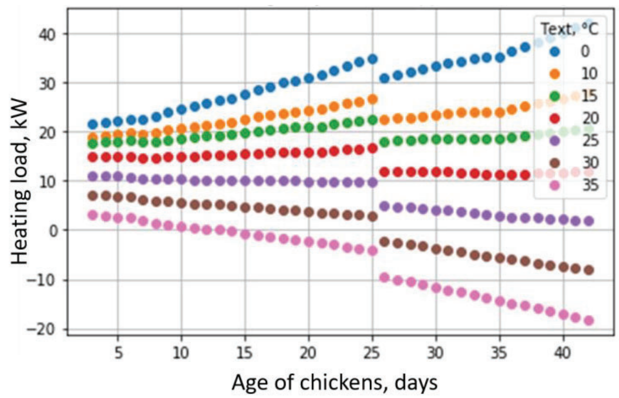

Figure 6. Heating load (sensible) for one department put under heat stress (720 chickens/compartment). RH (outside) = 50%.

3.3.2. Cold stress tests

The cooling loads for the three compartments during the cold stress tests are plotted in Figure 7, again in function of outdoor temperature and the age of the chickens. The gaps in this figure are once again a result of the change in setpoint condition as listed in section 2.2. The cooling load increases with an increase in outdoor temperature. At the lower outdoor temperatures, heating is required (indicated by the positive values) although reduced compared to the standard conditions. Once again, for the cold stress test conditions at an outside condition of 20°C, the required cooling power for one department is not exceeded for the standard conditions of one department at 35°C outside temperature.

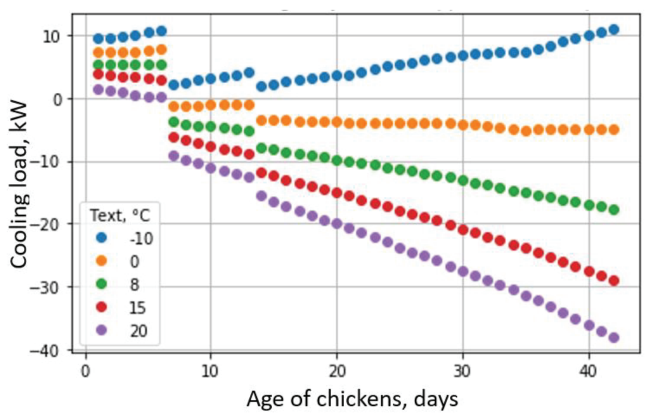

Figure 7. Cooling load (sensible) for one department put under cold stress (720 chickens/compartment). RH (outside) = 50%.

Combining the above mentioned results with the results presented in Table 3 (but rescaled to 6 compartments instead of 9) gives the total heating or cooling load of the entire farm during the periods with stress tests. It should be noted that these values are stationary loads, i.e. loads required to maintain the target temperature inside the compartments. However, in order to reach these temperatures within the required timeframe (2 hours), additional power is required, which can be based on dynamic calculations. As long as these tests occur at corresponding weather conditions, i.e. heat stress tests around summer time and cold stress tests around winter time, no additional power should have to be foreseen (compared to the values mentioned in Table 3) to be able to achieve the predefined conditions.

3.4. Sensitivity analysis of simulation parameters

In the calculations discussed above, several assumptions were made in the model. In this section, the influence of some of these assumptions on the results are investigated. A closer look will be taken at the air tightness of the farm and the applied ventilation strategy. The heating and cooling loads are recalculated with a different set of parameters, for the maximum and minimum loads during winter (-10°C outside) and summer (30°C outside) for 720 chickens per compartment.

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3.4.1. Influence of air tightness

As already mentioned in section 2.4, a default value of 1 ACH was applied in the simulations. The next graph illustrates the influence on the results when the infiltration rate is either halved or doubled. The influence on the cooling load is rather limited compared to the influence on the heating load. This is also illustrated by the energy balances presented before (Figure 3 and Figure 5). During winter conditions, when heating is necessary, the infiltration rate has a large relative contribution in the energy balance. However, during summer conditions, when cooling is required, the infiltration rate has a less dominant contribution. Overall, a good air tightness is important as it drastically impacts the heating load.

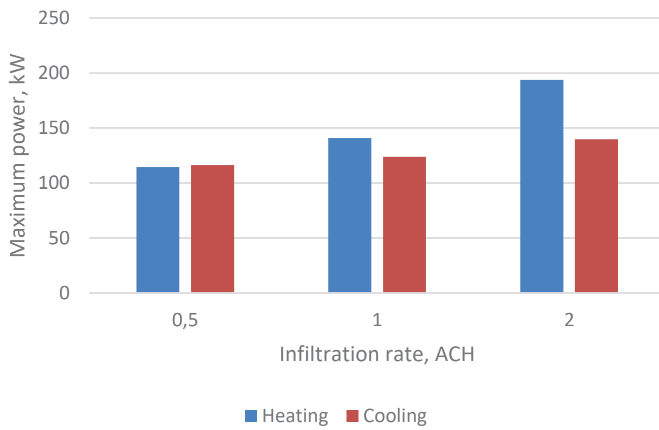

Figure 8. Influence of air tightness on (sensible) heating load (winter, -10°C) and cooling load (summer, 30°C) for the full stable (720 chickens/compartment at 42 days old). RH (outside) = 50%.

3.4.2. Influence of applied ventilation strategy

As a default, in the previous results, the minimum ventilation strategy was applied. In Figure 7, the influence of the choice of bandwidth in the strategy depicted in Figure 1 is investigated. In case cooling is required, first, 'free cooling' is used until the maximum ventilation flow rate is reached before active cooling is applied. The bandwidth "zero" means that the target temperature (TT) is always reached. For the "small" bandwidth, there is a 0.5°C tolerance on the target temperature (meaning T0 and T1 from Figure 1 are 0.5°C below and above TT, respectively). The bandwidth itself (difference between T1 and T2) is set to 2.5°C. This means that for this case, active cooling is started when the temperature is 3.5°C above the target temperature. The bandwidth "large" corresponds to a tolerance of 1°C on the target temperature and an actual bandwidth of 5°C, so active cooling will be started when the temperature is 7°C above the target temperature. From Figure 9, it can be seen that the influence of the ventilation strategy on the heating load is limited. This is because the tolerance on the temperature to apply heating is small in every case. For cooling, the tolerance is a lot higher. Only in a limited amount of cases, the outdoor temperatures will be 7°C higher than the target temperature, thus eliminating the need for additional cooling in a lot of scenarios.

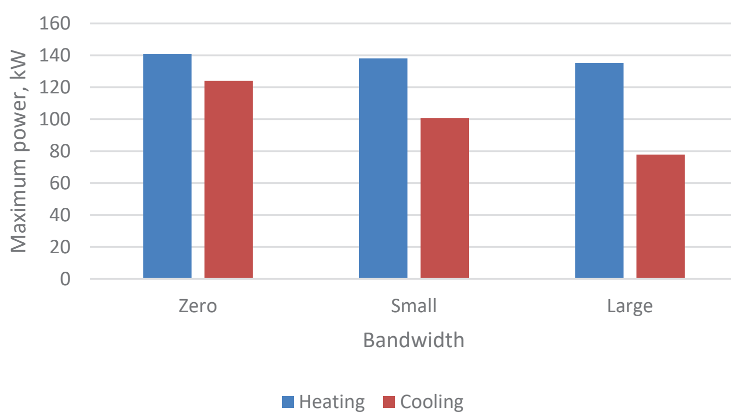

Figure 9. Influence of ventilation strategy on (sensible) heating load (winter, -10°C) and cooling load (summer, 30°C) for the full stable (720 chickens/compartment at 42 days old). RH (outside) = 50%.

3.5. Influence of outdoor relative humidity

The outdoor relative humidity has almost no impact on the sensible load but it does drastically change the total load through the latent heat requirements. Figure 10 shows the maximum humidifying and dehumidifying flow rate in function of the outdoor relative humidity. For humidification, this maximum occurs at the lowest outdoor temperature (-10 °C) and chickens of 14 days old. These values are almost constant as the saturated humidity ratio at this temperature is very low, resulting in only small changes of water content within the air flows. The maximum dehumidification flow rate occurs at the highest tested outdoor temperature (35 °C) and chickens of 42 days old. This value is more strongly dependent on the relative humidity as a similar change at this outdoor temperature represents a larger change in humidity ratio. At low relative humidities, dehumidifying is not necessary in any scenario. But at high relative humidities, the dehumidification has to balance the water vapour production from the chickens, infiltration flow rate, and ventilation flow rate, thus resulting in high required flow rates.

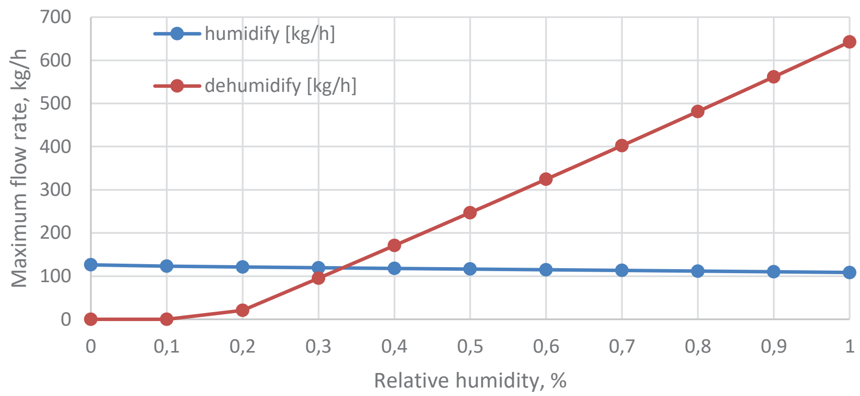

Figure 10. Influence of the outside relative humidity on the maximum required (de)humidifying flow rate for the full stable (720 chickens/compartment).

4. Simulation results over an entire year

Lastly, four simulations run over an entire year are compared based on representative weather data of the planned building location. The weather data is from a past year with measurements for every hour. The typical load for the planned farm is 720 chickens in each compartment, which grow over a period of 42 days. Before the next cycle of chickens occurs, an empty period of 10 days is required. A full cycle thus takes around 52 days. Four profiles are used to study the impact of when this 52 day cycle starts throughout the year. In the four different profiles the new chickens were introduced on days 1, 11, 26, and 40 of the year, where the rest of the occupancy is determined based on the 52 day cycle. The results of these simulations are presented in Table 4. There is some impact on the required heating and cooling depending on when the cycle is started. Some outliers are possible, as for example, the cooling demand for profile 2 is noticeably higher. The total cooling and heating loads presented in Table 4 also include the required cooling and heating to dehumidify, by cooling the air below the dew point and afterwards heating the air back to the required inlet temperature. The high cooling load in profile 2 is therefore also likely a result of the high dehumidification within this profile as a result of the unfortunate matching of this profile with a harsh weather period. It would thus be a good practice to try and match the 10 days empty period with harsh weather conditions if these are known sufficiently in advance.

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Table 4. Simulations over a year for a representative weather year.

		Profile 1	Profile 2	Profile 3	Profile 4
Total heat load	MWh/y	521.1	519.2	523.5	515.4
Sensible heat load	MWh/y	286.8	284.4	288.3	285.2
Total cooling load	MWh/y	88.0	106.2	94.3	78.4
Sensible cooling load	MWh/y	29.0	35.0	34.7	26.5
Max total heat load	kW	191.0	174.0	180.9	184.7
Max sensible heat load	kW	126.7	101.1	105.5	119.7
Max total cooling load	kW	221.6	253.5	227.0	222.7
Max sensible cooling load	kW	92.4	97.6	115.9	97.0
Total humidification	kg/y	304,649	300,165	306,645	300,710
Total dehumidification	kg/y	57,540	69,647	59,092	49,346
Max humidification flow rate	kg/h	105.3	111.5	107.8	98.6
Max dehumidification flow rate	kg/h	149.8	171.1	139.0	158.3

5. Conclusion

In this paper, a model was developed to estimate the heating and cooling demand, irrespective of the HVAC system, for a proof-of-concept chicken farm that would house a maximum of 14,000 chickens. During standard chicken occupation with 720 chickens per compartment, for a total of 6,480 chickens, the stable would require a maximum of 140 kW of heating load and 157 kW of cooling load depending on the weather conditions. These maxima occur for the oldest chickens of 42 days old. The main conduction losses of the stable are primarily through the floor and secondly through the ceiling. However, the implementation of underfloor heating could have a drastic impact on floor conduction losses. In the overall balance, the conduction losses are neglectable in comparison to the ventilation and infiltration losses. The air tightness of the chicken pens, however, is an important factor in the required heating power and sufficient effort should be taken to lower the air changes per hour of the air-conditioned stables. This stable will also be used to test the impact of stressful temperatures and humidities on the chicken's behaviour. The HVAC unit should also be able to handle these conditions. As long as these tests align with the reigning weather conditions, such as heat stress tests in summer, then there should be no additional power required to achieve the wanted stress conditions. The results of this model will help in sizing the required HVAC installations of the proof-of-concept chicken farm, leading to increased energy efficiency and reduction in greenhouse gas emissions.

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Nomenclature

ACH	air changes per hour, m^3/s
Q	thermal power, W
m	mass, kg
$\dot{m}$	mass flow rate, kg/s
RH	relative humidity, %
T	temperature, °C
TT	target temperature, °C
V	Ventilation rate, m^3/s

Subscripts and superscripts

a	air
ext	exterior

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