

Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	PiPoCool
Langtitel:	Climate change and future pig and poultry production: implications for animal health, welfare, performance, environment and economic consequences
Zitiervorschlag:	Schauberger G, Mikovits C, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Knauder W., Anders I., Andre K., Hennig-Pauka I., Schönhart M.: PiPoCool: Climate change and future pig and poultry production: implications for animal health, welfare, performance, environment and economic consequences. Endbericht, Klima- und Energiefonds, Wien
Programm inkl. Jahr:	ACRP8 (8th Call Austrian Climate Research Programme - ACRP), 2015
Dauer:	01.04.2016 bis 31.12.2018
KoordinatorIn/ ProjekteinreicherIn:	Vetmeduni Vienna (Veterinärmedizinische Universität Wien)
Kontaktperson Name:	A.Univ.-Prof. Dr. Günther Schauburger
Kontaktperson Adresse:	Veterinärplatz 1 A-1210 Wien
Kontaktperson Telefon:	0043 1 / 25077 - 4574
Kontaktperson E-Mail:	gunther.schauberger@vetmeduni.ac.at
Projekt- und KooperationspartnerIn (inkl. Bundesland):	Central Institute for Meteorology and Geodynamics (ZAMG), Wien University of Natural Resources and Life Science (BOKU), Wien
Schlagwörter:	Klimawandel, globale Erwärmung, Nutztiere, Stallhaltung, Schwein, Geflügel, Gesundheit, Hitzestress, Umwelt, Ökonomie

Allgemeines zum Projekt	
Projektgesamtkosten:	341.135 €
Fördersumme:	300.000 €
Klimafonds-Nr:	B567131
Erstellt am:	09.05.2019

B) Projektübersicht

1 Kurzfassung

Schweine und Geflügel werden in Österreich vorwiegend in geschlossenen Stallungen gehalten. Aufgrund der Wärmeabgabe der Tiere liegt die Stalltemperatur in herkömmlichen Stallungen im Sommer mindestens 2 bis 3°C über der Außentemperatur, was die Hitzebelastung der Tiere deutlich verstärkt. Sie reagieren auf Hitzestress durch Einschränkungen des Wohlbefindens (z.B. vermehrtes Hecheln), gesundheitliche Beeinträchtigungen (z.B. Mortalität), und eine verringerte Leistung (Mast- und Legeleistung).

Die Haltung von Schweinen und Geflügel hat mit 30% der Bruttowertschöpfung einen hohen Anteil an der Wertschöpfung in der österreichischen Landwirtschaft (BMLFUW, 2017). Die Auswirkungen des Klimawandels auf die Tierproduktion können nicht unmittelbar aus den Klimamodellen abgeleitet werden, sondern bedürfen komplexer Stallklimamodelle. Für den Landwirt sind Informationen über das Auftreten von Hitzestress nur von mittelbarer Bedeutung, da daraus keine Handlungsmaximen abgeleitet werden können. Auf Basis der zu erwartenden Veränderungen der ökonomischen Leistung (bspw. des Deckungsbeitrags) kann der Landwirt jedoch entscheiden, ob der Einsatz von Adaptationsmaßnahmen ökonomisch sinnvoll ist.

Anhand des beobachteten Klimawandels wurde die zeitliche Zunahme der Häufigkeit und der Intensität von Hitzestress landwirtschaftlicher Nutztiere untersucht. Dazu wurden die meteorologischen Messwerte von 1981 bis 2017 herangezogen, um das Stallklima für diesen Zeitraum zu simulieren (Schauberger et al., 2000). Das Stallklima beschreibt die thermische Situation sowie die Luftqualität für die Tiere und ist nicht nur von den meteorologischen Außenbedingungen, sondern auch von der Wärmeabgabe der Tiere, den thermischen Eigenschaften der Gebäudehülle und, bei zwangsbelüfteten Stallungen, von der Lüftungsanlage abhängig.

Für Tiere in Stallungen werden verschiedene Hitzestressparameter herangezogen. Im Weiteren werden unter Hitzestress jene Zeiten verstanden, in denen die Stalltemperatur über 25°C (= Sommerstunden) liegt bzw. eine Überschreitung des Temperatur-Feuchte-Index THI (Kombination von Lufttemperatur und Feuchtigkeit) von 75 vorliegt (Mikovits et al., 2018). Die Berechnungen wurden für einen Schweinemaststall vorgenommen.

Der Hitzestress wurde für den Zeitraum von 1981 bis 2017 berechnet. Die Häufigkeit der Sommerstunden hat sich um 13% pro Dekade erhöht, der kritische THI wurde um 30% häufiger überschritten. Da die tierische Leistungsfähigkeit mit dem Auftreten von Hitzestress deutlich abnimmt, führt dies zu ökonomischen Einbußen, etwa zu einer verringerten Futteraufnahme und einer damit verbundenen Verringerung der Mastleistung. Weiters führen

Hitzeperioden zu einer Verringerung des Tierwohls und der Gesundheit bis hin zu einer Erhöhung der Mortalität.

Zu den betrachteten Anpassungsmaßnahmen zählen energiesparende Luftaufbereitungssysteme und Maßnahmen, die einerseits die Abgabe der Wärme der Tiere verringern (z.B. weniger Tiere im Stall) und andererseits die Abfuhr dieser Wärme durch die Lüftungsanlage verbessern. Für diese Systeme wurde der Reduktionsfaktor bestimmt, der die prozentuelle Verringerung der Häufigkeit und der Intensität von Hitzestress angibt .

Drei verschiedene Luftaufbereitungssysteme wurden untersucht (Vitt et al., 2017). Der **Bodenspeicher** (Schotterspeicher) nutzt den Erdboden als Wärmespeicher. Dazu werden Rohre mit einer Länge von etwa 40 m in etwa 2 m Tiefe parallel im Boden verlegt. Die Zuluft des Stalls wird dann durch diese Rohre angesaugt. Das führt im Sommer zu einer Kühlung und im Winter zu einer Erwärmung der Luft, ähnlich dem Effekt in einem Keller. Weiters werden kurzfristige Temperaturschwankungen wirksam gedämpft. Der Reduktionsfaktor des Hitzestresses beträgt 93%, wobei zusätzlich durch die Erwärmung der Zuluft im Winter die Luftqualität durch eine verstärkte Lüftung verbessert wird. Der Nachteil des Bodenspeichers sind die hohen Investitionskosten und der Flächenbedarf zur Verlegung der Rohre. Die beiden anderen Luftaufbereitungssysteme nutzen das Verdunsten von Wasser zur Kühlung der Zuluft des Stalls. Das System **Cooling Pads** hat den Nachteil, dass zwar die Zuluft gekühlt, aber auch befeuchtet wird. Bei feuchter und sehr warmer Außenluft kann dadurch die Anwendbarkeit eingeschränkt sein. Der Reduktionsfaktor der Hitzebelastung beträgt 74%. Die Systeme mit **indirekter Kühlung** nutzen die Kühlung durch Verdunstung mit Hilfe eines Wärmetauschers auf indirekte Weise und führen zu einer Reduktion von etwa 61%. Obwohl dadurch die Investitionskosten steigen, besteht die Möglichkeit, den Wärmetauscher auch im Winterbetrieb zu nutzen, um damit die Wärmeverluste zu verringern und die Luftqualität im Stall durch eine höhere Lüfrate zu verbessern.

Weitere analysierte Adaptationsmaßnahmen betreffen vorwiegend das Management der Tierhaltung. Dazu gehört die Reduktion der Anzahl der Tiere im Stall. Während der Sommermonate wird die Tierdichte auf 80% und 60% reduziert und damit im gleichen Ausmaß die Wärmeabgabe der Tiere verringert. Dadurch kann Hitzestress um 4% bzw. 8% verringert werden. Durch die Verdoppelung der maximalen Auslegungsleistung der Ventilatoren, kann die abgegebene Tierwärme im Sommer verbessert abgeführt werden, was zu einer Reduktion der Hitzebelastung von 34% führt. Die Verschiebung der Aktivitäts- und Ruhezeiten um 10 Stunden stellte eine zusätzliche Managementmaßnahme dar. Dadurch geben die Tiere die zusätzliche Wärme, die durch hohe Aktivität und Fütterung entsteht, während der kühleren Nachtstunden ab. Während des Tages fallen die höheren Außentemperaturen mit den Ruhezeiten der Tiere und damit einer geringeren Wärmeabgabe zusammen. Das reduziert den Hitzestress um 23%.

2 Executive Summary

Pigs and poultry are predominantly kept in confined livestock buildings in Austria. By modelling the relationship between animals, building, and the ventilation system, the indoor thermal climate, air quality, and airborne emissions can be simulated. The simulation of the indoor climate (thermal parameters and air quality) for the confined livestock houses is driven by the meteorological parameters. We used a meteorological dataset (1981-2017) with a temporal resolution of one hour. These calculations were performed for two model areas with a high density of pig and poultry farms in Upper Austria (Wels) and in Styria (Feldbach). By the simulation model of the indoor climate of the livestock buildings the environmental situation of the animals and the effectiveness to reduce heat stress for animals was evaluated to increase the resilience of livestock husbandry.

The heat stress of animals was assessed by animal specific thermal indices which can be used to estimate animal welfare. Animal performance was expressed by daily weight gain, feed conversion, laying performance, mortality etc. The environmental impact can be assessed by the annual emission rate of NH_3 and odour. To alleviate heat stress we investigated the efficacy of several adaptation measures.

Results and conclusions

As a first step we investigated heat stress of a reference system for fattening pigs for a business as usual scenario to assess the resilience of confined livestock systems. For this system we could show that the indoor climate has a lower resilience compared to the outside situation. This simulation over 37 years resulted in an increase of the mean relative annual heat stress parameters in the range between 0.9% and 6.4% per year since 1981. In order to minimize the negative economic impact as the consequence of this positive trend of heat stress, adaptation measures are needed. The calculations for growing-fattening pigs show that such a simulation model for the indoor climate is an appropriate tool to determine the level of heat stress of livestock inside confined livestock buildings.

In the next step we analysed several adaptation measures to reduce heat stress. Seven adaptation measures were selected including three energy saving air preparation systems, the increase of the maximum ventilation rate, the reduction of stocking density, and the shift of the feeding and resting time pattern. The effect of these measures was quantified by the use of several heat stress metrics. The highest reduction of heat stress in comparison to the business as usual reference building was achieved by the three air preparation systems in the range of 74% to 92% for adiabatic systems and 90% and 100% for earth-air heat exchanger, followed by the increase of the ventilation rate, and the time shift. The reduction of the stocking density showed the lowest improvement.

The environmental impact was investigated for NH_3 and odour emissions. For ammonia emission, a relative increase of 0.16% per year was determined. But following the clean air endeavour between 1990 and 2015, emissions over that period were reduced by 23%. The global warming signal counteracts this reduction in the range of 4% over this period, which means that the overall reduction for the ammonia emission was only 19%. For Austria with a global warming increase of 1% from 1990 to 2015, this gives an increase in emissions of 5% instead. Odour emissions also increased by about 0.16% per year. The relative increase of the separation distances for the four cardinal directions was about 0.06% per year, the related increase for the separation area was 0.13% per year. This case study on the fattening pigs shows that the global warming signal has a negligible impact on separation distances.

Summary and Outlook

This project focused on the occurrence of heat stress inside confined livestock buildings. By this assessment, it could be shown that livestock buildings show a lower resilience than the outside situation. The temporal trend of heat stress parameters for fattening pigs shows an impact of 13% per decade for the frequency of summer hours (indoor temperature above 25%) and 30% for the exceedance of the temperature humidity index $\text{THI} > 75$. The extrapolation of the meteorological data between 1981 and 2017 was used as a conservative prediction of the future of the global warming. These calculations were performed for a reference building which is typical for livestock farms in Central Europe. To increase the resilience of the reference building, several adaptation measures were analysed to reduce heat stress. The first group of measures are energy saving air preparation systems, the second group are management measures. The air preparation systems (earth-air heat exchanger, cooling pads and a combination of cooling pads and heat exchanger) showed a reduction of the heat stress parameters in the range between 60% and 95%. The management measures like the reduction of the animal density during summer time, increase of the maximum ventilation rate of the ventilation system etc. show a weaker reduction performance between 5 and 51%. The impact of global warming on the ammonia and odour emissions shows an increase by 1.6% per decade. The increase of the ammonia emission will diminish the success of clean air initiatives in Europe. The impact of climate change modified odour emission rate on the separation distance as a protection against odour annoyance calculated with the chosen meteorological data set can be neglected.

Future aspects of this project should answer the question of how climate change affects the annual variability and temporal trend of the marginal income of livestock keeping in confined buildings. In this context, adaptation measures to reduce heat stress of the animals can be economically evaluated and examined for their applicability.

For livestock farmers, the effects of climate change are only of indirect importance with regard to the frequency of heat stress or heat days, due to the

fact that on the basis of this information no decisions and measures can be derived. By the use of the marginal income, the farmer can decide if adaptation measures are an economically useful tool to reduce the impact of climate change. With the aid of such an economic measure, decisions can be argued in a traceable and a better communicable way.

3 Hintergrund und Zielsetzung

The majority of pigs and poultry in mid-latitudes are kept in confined livestock buildings with a mechanical ventilation system (Robinson et al., 2011); at the global level, it is more than half (Niamir-Fuller, 2016). In the last decades global warming has already been a challenge which causes heat stress for animals in such systems. Nevertheless, the ability of livestock to tolerate heat stress declines with increasing performance levels, i.e. milk yield in dairy cows, growth rates and proportion of lean meat in pigs or poultry (Dikmen and Hansen, 2009; Hoffmann, 2013; Zumbach et al., 2008). In pig production, heat stress has been reported to reduce profitability (St-Pierre et al., 2003) but also affects the welfare of the animals (Huynh et al., 2005).

The following aspects were investigated in the PiPoCool project: (1) sensitivity of the indoor climate inside confined livestock buildings in relationship to global warming to assess the resilience of industrialised livestock keeping systems, (2) assessment of the effects of heat stress on production performance and welfare state of animals, (3) evaluation of adaptation measures to reduce heat stress in comparison to a reference system in a business as usual mode, (4) impact of global warming on the ammonia and odour emissions of livestock buildings, (5) impact of global change on the dilution of airborne emissions in the atmosphere, (6) impact of global warming on the separation distances

4 Projektinhalt und Ergebnis(se)

The research activities were performed along the work packages. A big effort was undertaken to publish the results of the research in peer reviewed journals. On the basis of these publications the dissemination activities are undertaken.

WP 2: For the two areas SE-Styria and Upper Austria, representative observational sites have been identified, available for the time period 1981-2017 providing all meteorological parameters needed. Hourly resolved one-year reference time series per parameter have been generated based on these station data and by monthly fitting (ÖNORM EN ISO 15927-4). According to the mean climate conditions at the observational sites for possible future climate change assessment in the same region, hourly output from selected regional climate models provided by individual CORDEX partners have been prepared for the

recent time period of 1981-2017 and the future time period of 2036 - 2065. This time period was selected according to the life expectancy of livestock housing in the range of about 30 to 50 years. Due to the large amount and the ability of hourly meteorological data the set of different future climate scenarios is limited, but has been selected to cover a spread of possible future conditions. For both time periods mentioned before and all available model data the same method of calculation of one-year reference is applied fitted to the observed values.

WP 2 Meteorological data

Based on the one-year time series of hourly meteorological parameters of the two reference years, time series of stability classes with two different methods (KTA 1508 (2006), VDI 3782/6 (2017)) have been delineated, the KTA scheme using a combination of radiation balance and the wind speed, the VDI scheme of cloudiness and wind speed.

The two focus regions Upper Austria north of the Alpine chain (centred around Wels, 48.16°N, 14.07°E) and South-eastern Styria (centred around Feldbach, 46.95°N, 15.88°E) are located within class Cfb (warm temperature, fully humid, warm summers) following the climate classification of Köppen and Geiger ([c.f. Kottek et al., 2006](#)). Both are representative for large areas in Central Europe excluding the Alps.

A statistical analysis of the two stability schemes used revealed different sensitivities of these methods to climate change. The results of the different methods and the changes between the two climate scenarios are shown in Fig. 1. In the two figures, the stability classes are grouped from very stable (class I) to very unstable (class V). To summarize, the two stations show a difference in the forecasted changes. Using the cloudiness method (Fig. 1a), Feldbach shows an about 5 % decrease of very stable conditions and the same increase of neutral conditions at night. At Wels, the opposite is the case: there is an increase in very stable conditions by about 5 % and a slighter decrease for classes II and III/1. As in Feldbach, almost no changes in daytime stability will occur. When using the radiation balance to determine stability classes (Fig. 1b), small changes for all classes at both sites are to be expected. Again, these changes will be different for the two stations. At Feldbach, a slight decrease in the frequency occurs for very stable (class I) and very unstable conditions (class V); for all other classes except IV, a slight increase in the frequency of stability classes is expected. At Wels, again mostly the opposite will be the case: the frequencies for classes I and IV will increase, for all others slightly decrease.

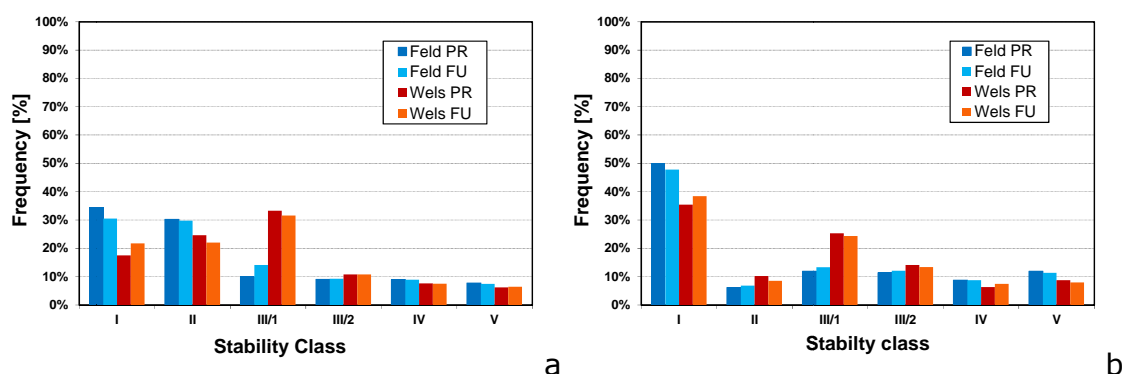


Fig. 1: Frequency distribution of stability classes determined by (a) cloudiness and wind speed (Table 1) and (b) radiation balance and wind speed (Table 2) at Feldbach and Wels (PR = present (1981-2010), FU = future (2036-2065))

WP 3 Simulation of the thermal indoor climate, air quality and airborne emissions

On the basis of the meteorological data which were elaborated in WP 2, the indoor climate was simulated by a steady state model which calculates the thermal indoor parameters (air temperature, humidity) and the ventilation flow rate. The thermal environment inside the building depends on the livestock, the thermal properties of the building, and the ventilation system and its control unit. The core of the model can be reduced to the sensible heat balance of a livestock building (Schauberger et al., 1999, 2000, 2001). The validation of the simulation model was elaborated for fattening pigs by measurements of Schauburger et al. (1995) and Heber et al. (2001).

The model calculations were focused on fattening pigs between 30 kg and 120 kg. The model calculations were performed for a typical livestock building for such pigs in Central Europe for 1800 heads, divided into 9 sections with 200 animals each. The reference system is characterised by the system parameters, which describe the properties of the livestock, the building, and the mechanical ventilation system.

An important feature of the model calculation is an animal growth model which is based on a Monte-Carlo simulation to avoid an interaction between the growth of the animals and the time course of the weather. For an all in-all out production system AIAO, an animal growth model describes the increase of the release of energy and CO₂ by the growing of the animal body mass of the herd. The time course of the body mass of growing-fattening pigs behaves like a saw tooth wave with a period of 118 d (about 1/3 of a year). These growth periods are superimposed and interact with the time course of the outdoor temperature. To create statistically valid results we calculated the body mass on the basis of a Monte Carlo method, called inverse transform sampling, a useful method for environmental sciences (e.g. Schauburger et al., 2013b; Wilks, 2011). There are

many techniques for generating a random sample which is distributed according to a pre-selected cumulative distribution function (CDF).

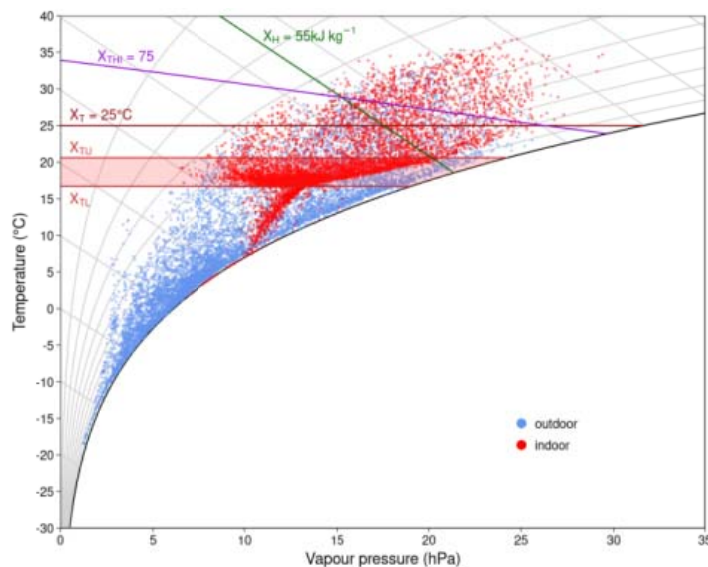


Fig. 2: Air temperature T and vapour pressure p for outdoor (inlet air, blue) and indoor (red) in 2003 as hourly data, depicted in a Mollier diagram (a rotated psychrometric chart). The relative humidity is shown by the series of curves in 10% steps. The indoor values are calculated for a constant body mass of $m = 105$ kg. The selected thresholds for the four heat stress parameters are depicted as coloured lines (temperature $X_T = 25^\circ\text{C}$, specific enthalpy $X_H = 55 \text{ kJ kg}^{-1}$, temperature humidity index $X_{THI} = 75$, and the controllable temperature range $X_{TL} = T_C$ and $X_{TU} = T_C + \Delta T_P$) (from Mikovits et al. (2018))

The calculations were done for 1981 to 2017 to determine the trend for the 37 year period. Additionally, we selected the years 1984 and 2003, as one of the coldest and warmest years, respectively, for summertime measured in the last decades, to show specific results outside of the trend calculations. The trend is estimated with a linear function $x_{trend} = b \cdot x + a$ for the period 1981 to 2017. The starting point of the linear trend is calculated for 1981 as a reference value. The outcome of the simulation model is evaluated by heat stress measures. Heat stress for pigs can be quantified by the following parameters and related threshold values (Vitt et al., 2017): (1) air temperature (dry bulb) T , (2) temperature-humidity index THI , and (3) specific enthalpy H , which is equivalent to the apparent equivalent temperature (Mitchell and Kettlewell, 1998). For all these parameters, a related threshold value X has to be defined (Fig. 2).

First of all these model calculations were performed for the reference building as a business as usual scenario. Beside the temporal trend between 1981 and 2017, the resilience of the reference system was determined.

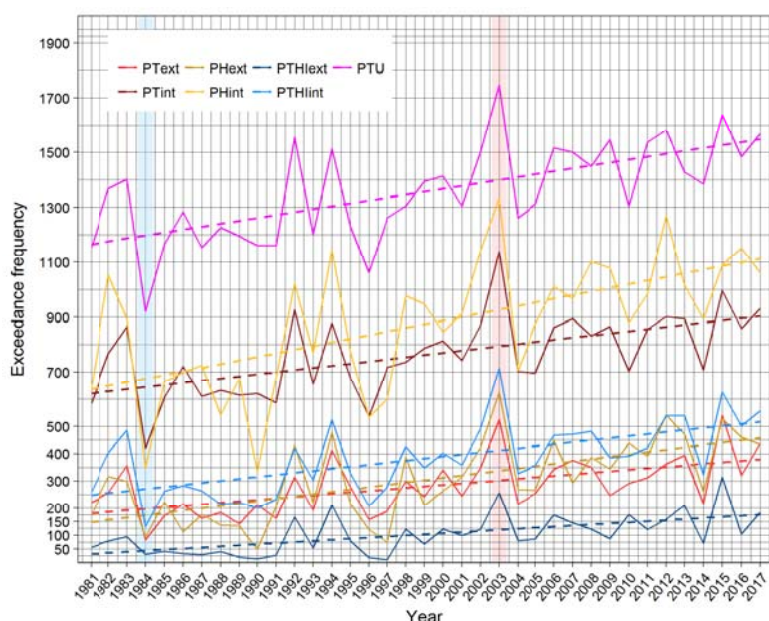


Fig. 3: Time course of the exceedance frequency P_x (h/a) of the thresholds for air temperature $X_T = 25^\circ\text{C}$, specific enthalpy $X_H = 55 \text{ kJ/kg}$, temperature humidity index $X_{THI} = 75$, and the controllable range X_{TU} for indoor (int) and outdoor (ext) (after Mikovits et al. (2018))

The simulation of the indoor climate of confined livestock buildings shows a lower resilience for global warming compared to the outside situation. The mean relative annual trend for heat stress parameters between 1981 and 2017 lies in the range between 0.9 and 6.4% per year, relative to the year 1981. The more frequent and more distinct occurring heat stress situations have an essential influence on the performance, health and welfare status of livestock. Future impacts of global warming will be even more severe. To reduce animal health and welfare problems as well as the economic impact of these changes, appropriate adaptation measures are needed. The selection has to focus on adaptation measures with low investment and operating costs. Long-term (seasonal) climate forecasts similar to those offered for crop producers would be essential for decision-making tools aiming at mitigating heat stress for livestock inside confined buildings. The calculations for growing-fattening pigs show that such a simulation model for the indoor climate of confined livestock buildings is an appropriate tool to determine conditions of heat stress for livestock.

The improvement of the indoor climate with respect to the expected heat stress is achieved by the following adaptation measures: **(1) Direct evaporative cooling: Cooling pads CP.** In confined livestock buildings, direct evaporative cooling devices are in use to convert sensible heat (air temperature) via evaporation of water into latent heat (humidity) with the major goal to reduce the inlet air temperature. We assumed cellulose as matrix to increase the wet surface. The efficacy of the CP was determined with 80%. **(2) Indirect**

evaporative cooling: Cooling pads combined with a regenerative heat exchanger CPHE. Indirect evaporative cooling systems result in a reduction of the inlet air temperature by evaporation without humidification. The outside air is cooled using direct evaporative cooling. Then this evaporatively cooled secondary air cools the outside air in a conventional air-to-air heat exchanger. We assumed CP and a downstream heat exchanger HE with a constant sensible efficiency of 65%. **(3) Earth-air heat exchanger EAHE** utilise the ground as a heat storage. Outside air flows through tubes with a diameter D in the range between 0.1 and 1.0 m and a length L between 20 m and 200 m, buried in a depth z between 1 and 3 m. EAHEs are well-investigated and practically tested energy-saving air treatment devices. The performance, i.e. air temperature and humidity at the end tubes, depends on the soil temperature T_s , the outside air temperature and humidity, the thermal features of the soil and the geometry of the tubes (Bisoniya et al., 2014; Ozgener, 2011; Tzaferis et al., 1992). All calculations were performed with the *number of transfer units NTU* method. The calculation of the model parameter for the sensible and latent heat transfer can be found in detail in Vitt et al. (Vitt et al., 2017).

The following adaptation measure are more related to the livestock management. **(4 and 5) Reduction of stocking density SD during summer season to 80% and 60%.** To reduce the animal heat release during the warm season, the stocking density was reduced. For those fattening periods which are starting between the 57th and the 119th day of the year (about 1st March till 30th April), the SD was reduced. Two scenarios were calculated with a reduction to 80% (SD80%) and 60% (SD60%) compared to REF.

(6) Increase of the summer ventilation rate VENT. To reduce the increase of the indoor temperature due to the sensible heat release of the animals, the maximum ventilation rate was doubled. **(7) Inversion of the diurnal feeding and resting pattern SHIFT.** By a shift of the feeding and resting time pattern by about half a day, the maximum of the outdoor temperature coincides with the resting time. The time shift of 10 hours was determined by the diurnal temperature variation of heat days (daily maximum > 30 °C).

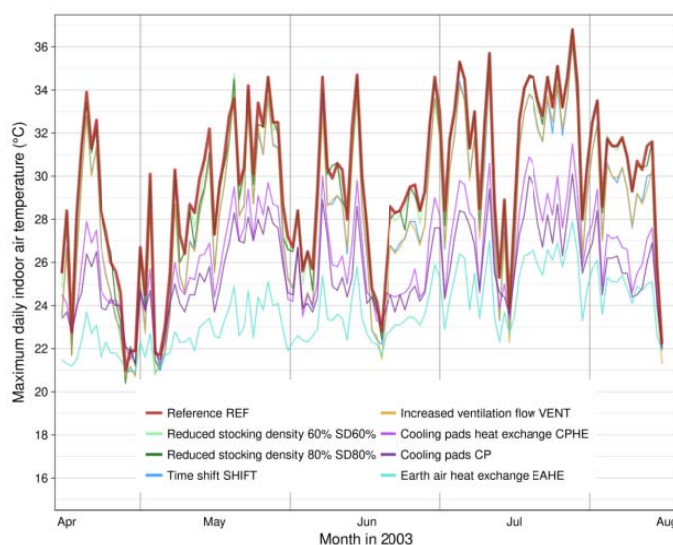


Fig. 4: Daily maximum of the indoor air temperature T for the summer months 2003 for the business as usual reference building REF and the seven adaptation measures AM: (1) cooling pads CP, (2) cooling pads with heat exchanger CPHE, (3) earth-air heat exchanger EAHE, (4) inverted diurnal time pattern SHIFT, (5 & 6) reduced stocking density by 80% (SD80%) and 60% (SD60%) and (7) increased ventilation flow rate VENT. (from: (Schauberger et al., 2018a))

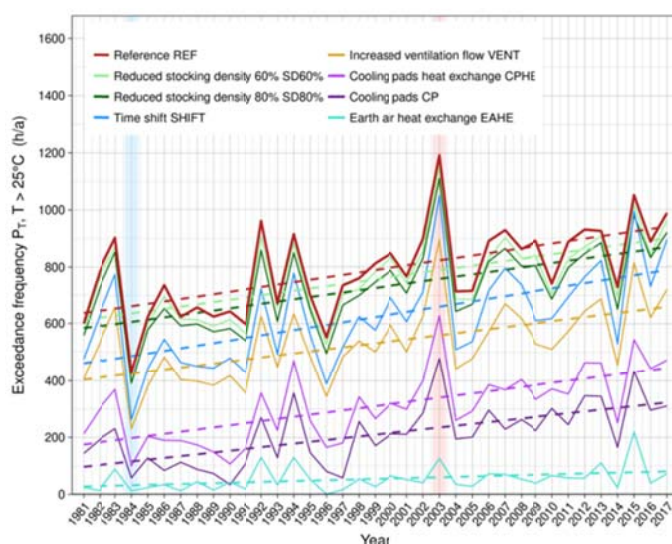


Fig. 5: Annual exceedance frequency PT (A) and exceedance area AT (B) for the threshold of the indoor air temperature $X_T = 25$ °C determined for the business as usual reference system REF and the seven adaptation measures AM: reduced stocking density SD80% and SD60%, diurnal shift of the activity pattern SHIFT, the increase of the summer ventilation rate VENT, the cooling pads plus heat exchanger CPHE, cooling pads CP, and Earth air heat exchanger EAHE. The linear regressions are shown by dashed lines. (from: (Schauberger et al., 2018a))

The results of the air preparation devices show that the EAHE is the most efficient air treatment device. It eliminates heat stress depending on the selected heat stress parameter between 90% and 100% and can also be used during wintertime to increase the inlet air temperature. This will increase the air quality as well. CP will reduce heat stress by 74% to 92% with the disadvantage that the inlet air will be moistened. CPHE can avoid this shortcoming at the expense of a limited heat stress reduction between 61% and 86% and higher investment costs. Nevertheless, the profitability of both management-based AM and these air preparation AM has to be investigated. The weakest performance was calculated for the reduction of the stocking density with a reduction factor below 10% of most of the heat stress measures. The reduction factors for SHIFT and VENT are between 22% and 51%.

Ammonia and odour are the most relevant pollutants emitted from livestock buildings used for monogastric animal production. Whereas odour can cause annoyance in the close vicinity of the source, emission of ammonia is a precursor for the formation of particulate matter and acidification on a regional scale. NH_3 is an important precursor of fine particulate formation in the atmosphere (Backes et al., 2016a; Backes et al., 2016b; Xu and Penner, 2012). It plays a crucial role in the acidification and eutrophication of ecosystems, and contributes to indirect emissions of nitrous oxide. The relation between emission and concentration of NH_3 shows a complex pattern. After the emission, NH_3 is transported in the atmosphere. It is chemically transformed into secondary non-gaseous inorganic aerosols such as ammonium nitrate and ammonium sulphate and it is removed from the atmosphere by dry and wet deposition (van Zanten et al., 2017). Agriculture has been identified as the major source of atmospheric NH_3 , contributing 55–56% of the global emissions (Sutton et al., 2013). For Europe, about 94% of NH_3 emissions are related to agriculture (EEA, 2017).

The release modification was calculated on the basis of the indoor air temperature, ventilation rate, and physical activity of animals as a function of daytime t (Schauberger et al., 2013a; Schauburger et al., 2014), which is driven by the simulated indoor climate parameters.

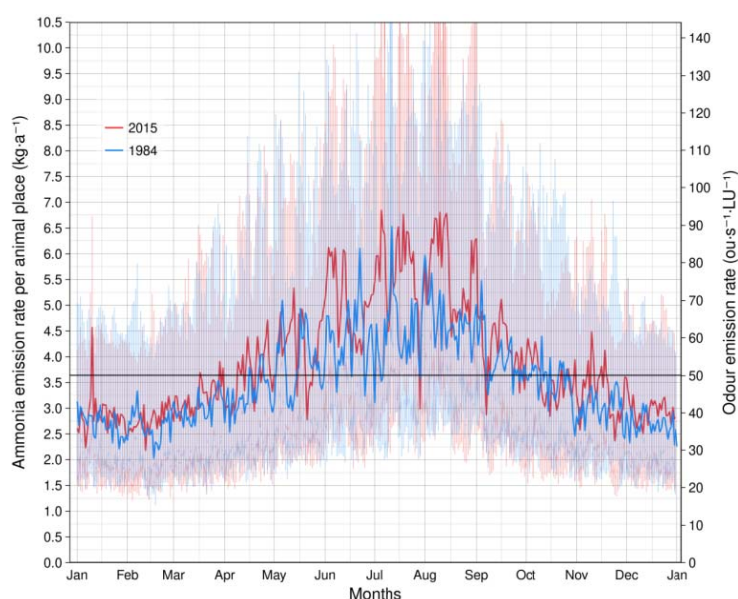


Fig. 6: Time trend of the hourly values of the NH₃ emission rate per AP e_{NH_3} (kg a⁻¹) and the body mass related odour emission rate e_{OD} (ou s⁻¹ LU⁻¹) for 1984 (cold, in blue) and 2015 (warm, in red). The reference values for NH₃ and odour emission factors are $e_{NH_3,0} = 3.64$ kg a⁻¹ and $e_{OD,0} = 50$ ou s⁻¹ LU⁻¹, respectively, which are depicted by a thin black line. The two lines for 1984 and 2015 represent diurnal mean values of the odour and NH₃ emission. (from Schaubberger et al. (2018b)).

The impact of the global warming signals shows an increase of the NH₃ emission of confined livestock buildings. This increase lies in the range of about 4% which diminishes the reduction of 23% achieved between 1990 and 2015 by clean air activities. The distinct annual variation of the emission rate shows that a constant annual emission factor cannot be used to estimate the ambient NH₃ concentration by chemistry transport models.

The odour emission of livestock buildings was simulated for more than three decades to investigate the impact on the annual mean emission factor. In addition to meteorological factors, emission factors are relevant to calculate the separation distance to avoid odour annoyance. The economic consequences of odour were investigated by examining the separation area which is circumvented by direction dependent separation distances. The relative trend of the odour emission lies in the range of about + 0.16% per year which gives an increase of about 3% between 1981 and 2017. The relative increase of the separation distances for the four cardinal directions is about 0.06% per year and the related increase for separation area is 0.13% per year. For this case study for fattening pigs it has been shown that the climate change signal has a negligible impact on separation distances. Therefore, the current and near future zoning and licensing of livestock buildings is based on reliable emission data.

WP 4 Interaction between animals and their thermal environment: Performance, health and welfare response to heat stress

Effects of heat stress on performance traits, health status and welfare aspects were analysed based on literature data, i.e. from feeding trials with pigs and chickens in confined houses with controlled thermal environments. Functions for heat stress impacts were derived for the following production traits: body mass gain (for pigs and broilers), egg mass (for laying hens), feed intake, feed conversion ratio and mortality. All impacts were derived as changes applied to basal Gompertz functions or linear functions for the specific traits, which have been identified for different animal categories and a given range of age and body mass.

Thermoregulation consists of four major heat loss mechanisms, which occur if the ambient temperature is above the "thermoneutral zone": conduction (i.e. heat transfer between two bodies with direct contact; e.g. an animal lying on a colder floor), convection (heat transfer via moving media like air, water or blood; e.g. used for ventilation systems), radiation (heat exchange in the form of electromagnetic waves; relevant for e.g. pastured animals at night), and evaporation (heat loss by evaporation of water from the animal's skin and respiratory tract; Hafez 1968, Von Engelhardt 2010, Breves et al. 2015).

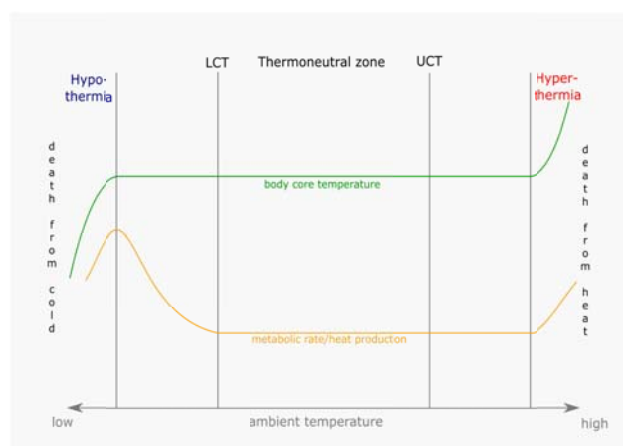


Fig. 7: Simplified scheme of thermoregulation with the thermoneutral zone (TNZ), upper critical temperature (UCT), lower critical temperature (LCT), body core temperature, ambient temperature and metabolic rate.

Below and above a certain temperature zone, animals are no longer able to maintain their core temperature on a constant level and hypothermia or hyperthermia occur (Fig. 7). The critical upper limit for the body core temperature is about 42-45° C (hyperthermia). The limits of the thermoneutral zone for pigs and poultry depend on body mass and age of the animals and vary widely in the literature. Tab. 1 shows average, minimum and maximum

temperatures for thermoneutral zones of domesticated pigs and recommendations for temperatures in chicken houses based on various sources (see Tab. 2 for literature sources). It has to be noted, that these temperature values differ with corresponding humidity values.

Tab. 1: Thermoneutral zones (TNZ) of domesticated pigs and recommendations for temperatures in chicken houses (°C)

Animal category	Average / Min / Max	Animal category	Average	Animal category	Average
Suckling piglets (<7 kg)	26-32 / 22 / 33	Pullet, day 1-2	35-36	Broiler, day 1-3	35-33
Weaned piglets (8-30 kg)	23-29 / 20 / 30	Pullet, day 3-4	33-34	Broiler, day 4-5	32-30
Growing pigs (30-60 kg)	19-22 / 18 / 25	Pullet, day 5-7	31-32	Broiler, day 6-9	28-27
Finishing pigs (>60 kg)	17-21 / 15 / 24	Pullet, week 2	28-29	Broiler, day 12-15	25-24
Sows, after weaning	16-20 / 15 / 20	Pullet, week 3	26-27	Broiler, day 18-21	23-22
Sows, lactating	18-22 / 16 / 22	Pullet, week 4	22-24	Broiler, day 24-27	22-20
Boars	18 / 16 / 19	Pullet/layers, ≥5 week	18-20	Broiler, day ≥27	20

Tab. 2: Literature sources and effects derived for temperature requirements, thermo-neutral zones (TNZ) and heat stress-temperatures as well as effects of temperature increases on production traits.

	Literature sources for...	
Animal category	Temperature requirements, thermo-neutral zones and heat stress	Temperature effects on production traits
Broiler	<p>Al-Fataftah and Abu-Dieyeh (2007)</p> <p>Quinteiro-Filho et al. (2010)</p> <p>Aviagen (2014)</p> <p>Poultry Cooperative Research Centre Australia (s.a.)</p> <p>--> As a conclusion we assume a potential heat stress from day 21 onwards for ≥ 25 °C</p>	<p>Al-Fataftah, and Abu-Dieyeh (2007)</p> <p>May, et al. (1998)</p> <p>Quinteiro-Filho, et al. (2010)</p>
Laying hen	<p>Lohmann-Tierzucht (2012)</p> <p>Poultry Cooperative Research Centre Australia (s.a.)</p> <p>--> Temperature requirement in laying period 18 to 20 °C;</p> <p>--> Upper critical temperature, heat-response if exceeded: ≥ 24 °C (due to a reduction of egg shell quality und egg weight);</p> <p>--> upper critical temperature, heat-response for mortality if exceeded: >27 °C</p>	<p>Ugurlu et al. (2001)</p> <p>Mashaly, et al. (2004)</p> <p>Yahav, et al. (2000)</p> <p>Roberts and Ball (1998)</p> <p>Talukder, et al. (2010)</p> <p>Feizi, et al. (2012)</p>
Piglet, growing and fattening pig	<p>Troxler and Menke (2006)</p> <p>Bracke (2011)</p> <p>The Pig Site (s.a.)</p> <p>Whittemore and Kyriazakis (2006)</p>	<p>Berton et al. (2014)</p> <p>Song et al. (2014)</p> <p>White et al. (2008)</p> <p>Weller et al. (2013)</p> <p>Le Dividich et al. (1980)</p> <p>Rinaldo & Le Davidich (1991)</p>

		Lefacheur et al. (1991) Rinaldo et al. (2000) Collin et al. (2001ab) Collin et al. (2002) Ferguson and Gous (1997) Oliveira and Donzele (1999) Hyun et al. (1998) Lopez et al. (1991) Kouba et al. (2001) Becker et al. (1992)
--	--	---

Based on data from many scientific papers and reviews (Tab. 2), the following temperatures have been identified as the points where adaptation mechanisms start to occur for finishing and growing pigs (Fig. 8 and Fig. 9).

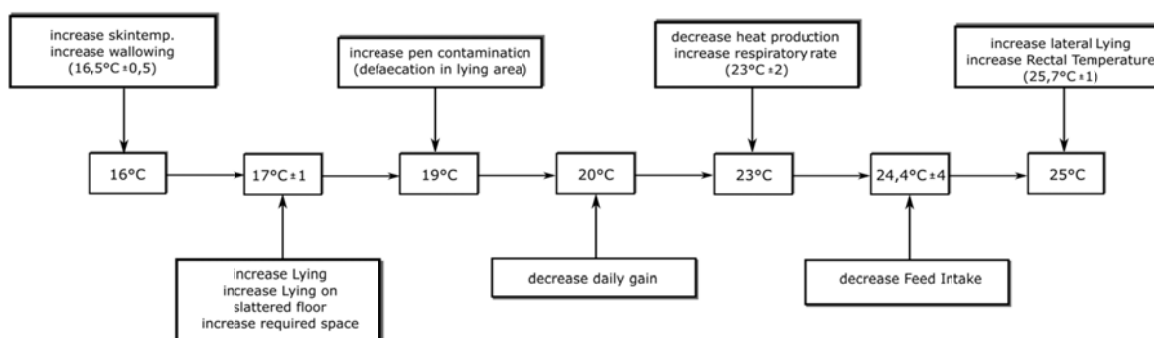


Fig. 8: Effect of temperature increases on adaptation mechanisms of pigs above 60 kg body mass (sows, boars, finishing pigs).

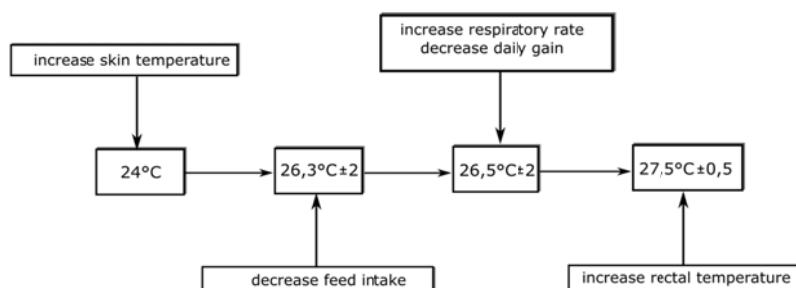


Fig. 9: Effect of temperature increases on adaptation mechanisms of (growing) pigs (30 to 60 kg body mass).

Similarly, chickens change their behaviour and activate thermoregulatory mechanisms, to maintain their body temperature and avoid suffering from hyperthermia (Fig. 10, literature sources given in Tab. 2). There are several physiological and behavioural functions and reactions to maintain homeostasis. Especially when thermal stress occurs rapidly and acute, the birds soon start to change their behaviour. Figure 5 shows the effect of a temperature increase on these behavioural changes and on performance of laying hens.

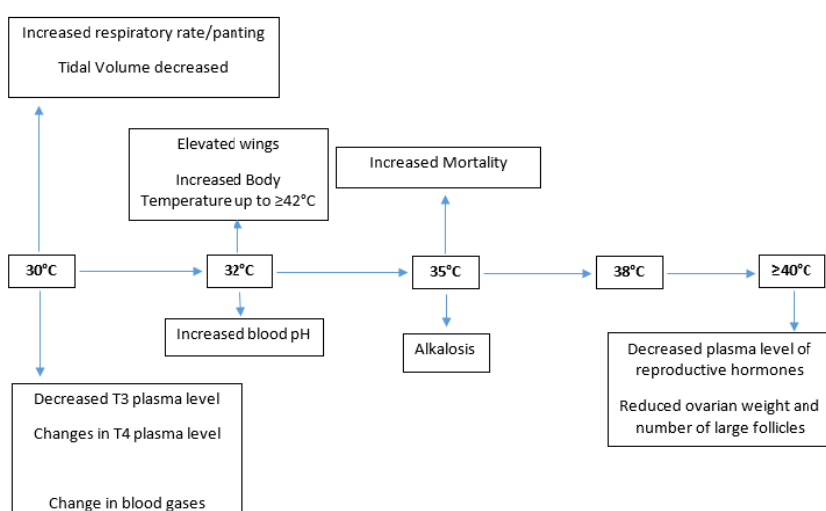


Fig. 10: Effect of temperature increase on adaptation mechanisms of poultry.

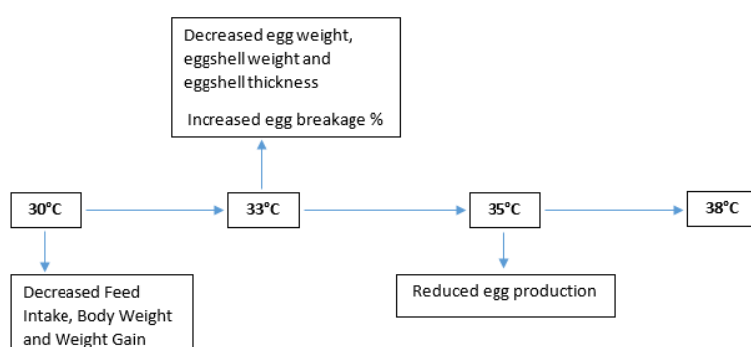


Fig. 11: Effect of temperature increase on performance of laying hens.

Too long durations with heat stress, especially with temperatures near the upper critical limits cannot be fully compensated anymore. When a decline in the adaptive thermoregulatory mechanisms becomes apparent, reduced well-being and, in severe cases, mortality occur (Johnson 2018; Fig. 2 – Fig. 5).

Combining all literature data collected (Tab. 2), critical temperatures for a beginning heat stress and its significant effects on production traits were

identified (Tab. 3). Furthermore, livestock category-specific responses to heat stress (regarding feed conversion ratio, feed intake, egg mass, body mass (gain) and mortality) were derived (Tab. 4). Due to a remarkably higher data availability for temperature-related effects of heat stress than for THI effects, more robust estimates could be identified for temperature-related changes. For THI-results, all studies with data on humidity (plus temperature, feeding and performance data) and the THI-model according to NWSCR (1976) were used. To verify a significant difference in performance at normal temperatures and THIs vs. that under heat stress conditions, a two-sample t-test was used.

For broilers and laying hens, no significant effects of increasing temperature could be derived from available data for feed conversion ratios. Comparably, no (significant) heat stress effect on growing and finishing pigs' mortality rates and on breeding sows' fertility was detected. Generally, no heat stress effect was found for the performances of weaned piglets (Tab. 4). The example of the weaned piglets shows that animals at certain ages and within specific body mass classes are less affected by higher ambient temperatures than others. For instance, no heat stress effects can be expected for broiler chickens until the fourth week of life.

Generally, the linear increments and reductions given in Tab. 4 describe quite well the findings from trials, as most of the analysed studies did not test heat stress temperatures near hyperthermia. Hence, our analysis showed that only under conditions of hyperthermia (i.e. substantially exceeding optimal temperatures), exponential relationships become apparent.

Tab. 3: Critical temperatures for the occurrence of heat stress and effects on production traits.

Livestock category	Trait	°C
Broilers*	body mass gain, feed intake, feed conversion, mortality	25
Laying hens	egg mass and egg (shell) quality, feed intake, feed conversion	24
	mortality	27
Growing/finishing pigs	body mass gain, feed intake, feed conversion and mortality	25/22
Sows	- no significant heat stress effect on fertility identified from literature -	-

(Suckling and weaned) piglets	- <i>no significant heat stress effect identified from literature</i> -	-
-------------------------------	---	---

* from day 21 onwards

Tab. 4: Effects of heat stress on production traits

	Significant difference between thermoneutral- and heatstress-conditions	Average change per 1° C temperature change	Average change per 1 THI unit
Broiler chickens			
Body mass gain	yes	-4.1 %	-4.0 %
Feed intake	yes	-2.1 %	-2.3 %
Feed conversion ratio	no	+3.6 %	+2.0 %
Mortality	yes	16.1 % (+2.1 % points)	11.7 % (+1.5 % points)
Laying hens			
Egg mass	yes	-1.2 %	-1.0 %
Feed intake	yes	-1.9 %	-1.7 %
Feed conversion ratio	no	+0.8 %	+0.9 %
Mortality	yes	23.3% (+2.0% points)	14.09 % (+1.3 % points)
Growing pigs (30-60 kg body mass)			
Body mass gain	yes	-2.4 %	-2.2 %
Feed intake	yes	-1.8 %	-1.6 %
Feed conversion ratio	yes	+0.6 %	+0.6 %
Finishing pigs (>60 kg body mass)			
Body mass gain	yes	-4.2 %	-3.2 %
Feed intake	yes	-3.2 %	-2.3 %
Feed conversion ratio	yes	+1.1 %	+0.9 %
Suckling piglets			
Body mass gain	no	-0.5 %	-0.5 %
Feed intake	no	-1.0 %	-0.4 %
Feed conversion ratio	no	+0.5 %	+0.8 %
Mortality	no	-1.5 %	-1.6 %

Breeding sows			
Conception rate	no (tending to significance)	-0.8 %	1.0 %

WP 5 Case study assessment: animal health, welfare, performance, environmental impact, and economic implications

The indoor climate simulation model quantifies indicators for animal health and welfare such as THI, temperature and humidity in the case study application for both the reference and adaptation measures (see figure 3 & 4 and description above). Livestock performance is estimated with the livestock yield simulation model. It is driven by the indoor climate indicators and based on a literature review (see WP 4 description above). FAMOS utilizes both the indoor climate results and the livestock yield simulation model (see Tab. 5) to estimate the economic implications of changing outdoor climate conditions. In FAMOS, livestock production and management choices are represented in detail and climate impacts determine feed intake, livestock growth and eventually mortality with feedbacks on feed costs, fertilizer production, variable costs and labor demand. Dietary standards are obligatory but can be met with varying feeding options. The timing of feeding determines feed up-take and indoor climate from body heat release. The inversion of feeding and resting cycles, i.e. feeding during night times, can mitigate heat stress and is considered as a management option. FAMOS chooses management options which lead to distinct expressions of climate parameters. These values are constrained by upper and lower thresholds to guarantee an indoor climate within the ranges of animal health standards. Indoor climate conditions are driven by operational management choices such as ventilation rates (increase of total air volume in summer by 100%) and strategic choices on technical adaptations to regulate climate. These investments are considered as annuities in the objective function. Total livestock numbers are constrained by the capacity of the facility given specific animal welfare standards, the feed supply, manure management standards, and farm labour availability. Livestock age and density impact indoor climate conditions via the release of body heat. FAMOS chooses between a 100%, 80%, and 60% level of livestock numbers compared to the facility capacity. Further management choices such as veterinary services are considered as costs but are kept invariable in the model.

Indoor climate parameters include daily THI and temperature values. A threshold determines the level above which performance impacts are expected resulting in reduced feed intake, growth and mortality (here not considered due to highly uncertain parameters; Tab. 5).

Tab. 5: Livestock yield parameters

Indoor climate indicators	Daily weight gain loss (%) ¹	Feed intake (%) ¹	Threshold (THI or Temperatur)	Mortality (%) ¹
THI_ave	2.9	2.1	75	0
TEM_ave	3.6	2.7	23	0
THI_max	2.9	2.1	75	0
TEM_max	3.6	2.7	23	0
No_clim_effect	0	0	0	0

Note: ¹ change per THI or temperature (TEM) points above threshold; threshold for heat stress impacts; ave: daily average value; max: daily maximum value.

Adaptation measures are parameterized by literature values on investment costs (i.e. to estimate annuities with a 2% annual interest rate), additional variable costs for electricity and water and additional labor demand (see Tab. 5).

WP 5 synthesized outputs from other work packages in a case study approach (Fig. 12). Major components are outdoor climate data, an in-door climate simulation model, a livestock yield simulation model, and a newly developed bio-economic farm optimization model (BEFM). WP5 applied the indoor climate simulation model (WP3) to quantify the indoor climate situation of a typical future livestock housing operation (Tab. 6) under a climate scenario (WP2). The model was applied to a reference management situation and a number of heat abatement measures, i.e. climate change adaptation measures including:

- direct evaporative cooling with cooling pads (CP)
- indirect evaporative cooling with cooling pads combined with a regenerative heat exchanger (CPHE)
- earth-air heat exchanger (EAHE)
- reduction of animal density during summer season (REDU)
- increase of the summer ventilation rate (VENT)
- inversion of the diurnal feeding and resting pattern (SHIFT)

Tab. 6: Properties of the livestock housing operation in the case study

Parameter	Value
Growing-fattening pigs, live weight	30-120 kg
Total number of pigs	1800, divided in 9 sections
Growing-fattening period	108 days
Facility service period	10 days
Production system	All in – all out

Both, indoor climate parameters from the indoor climate simulation model and parameters from the livestock yield simulation models about the relationship between climate parameters and livestock performance (WP4) enter the bio-economic farm optimization model FAMOS. FAMOS optimizes the annual total gross margin subject to farm resource, agronomic and policy constraints. Total gross margin equals the sum of farm revenues from crop and livestock production and subsidies minus variable production costs.

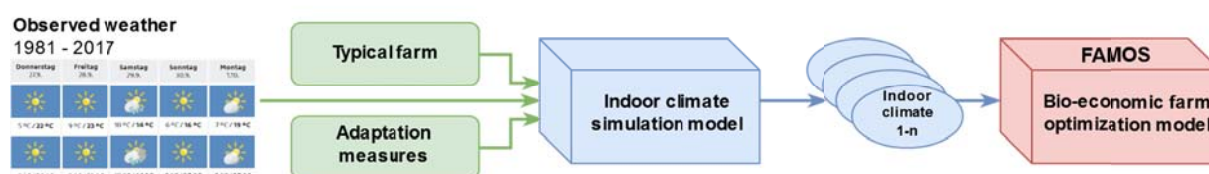


Fig. 12: Overview on PiPoCool case study analysis

The portfolio of management choices as well as the socio-economic and bio-physical framework conditions determine indoor air temperature, corresponding livestock yields, revenues, and production costs. The BEFM selects the portfolio that maximizes annual total gross margin.

Finally, direction-dependent separation distances have been estimated in WP5 to describe the effects of altered emission rates of climate conditions to stakeholders.

The environmental impacts in WP5 are assessed by modelling odour and ammonia emissions. For the reference farm units in the case study areas, dispersion calculations with LASAT have been conducted to calculate separation distances to protect the neighbourhood from odour annoyance for the current and future climate reference scenarios. Direction-dependent separation distances are a very practical means to describe the effects of altered emission rates or

climate conditions to the stakeholders. With respect to the selected climate scenarios and the variety of the stability schemes, a bandwidth of affected areas and separation distances resulted, with a possible judgement if and how, in the future, livestock husbandry will have to adapt to climate change.

Tab. 7 Additional investment and variable costs of adaptation measures

	Lifetime (yrs)	Invest cost (€)	Annuity (€)	Electricity (€)	Maintenance (€)	Water (€)	Var. Labor demand (h)
CP	12	14846	1404		100	211	10
CPHE	12	14846	1404		100	275	15
EAHE	30	4147	92883	-2340			
REDU							
VENT				260			20
SHIFT							50

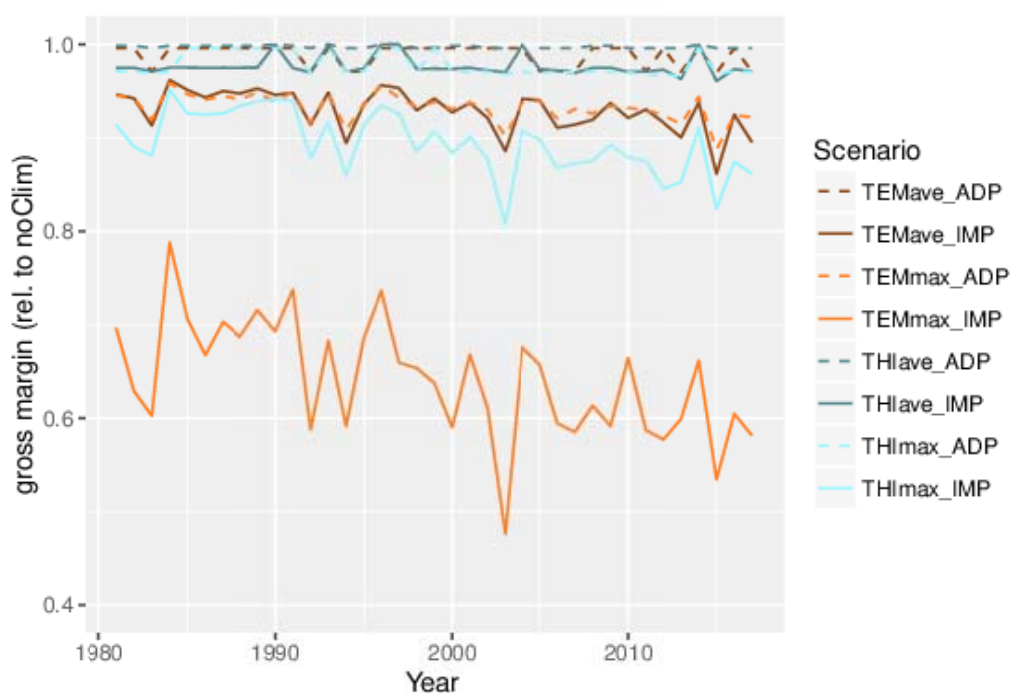


Fig. 13: Impacts in gross margins from different scenarios in FAMOS

We apply FAMOS to either indoor THI or temperature (TEM) and average (ave) or maximum (max) values in one scenario run to cover the uncertainty from parameter assumption. Furthermore, we define an impact (IMP) scenario without adaptation and an adaptation (ADP) scenario. Fig. 13 presents impacts from these scenario combinations on total farm gross margin in FAMOS. Results are compared to a reference situation without consideration of climate impacts (i.e. standard model values assuming a standard but undocumented climate

situation). Results strongly depend on the scenario assumptions. FAMOS based on maximum temperature effects without adaptation (TEMmax_IMP) shows the strongest impacts but likely has an unrealistic combination of parameters. In all cases adaptation reduces losses of gross margins. In a scenario assuming average THI values with adaptation (THave_ADP), losses can be fully covered by adaptation in most years. To conclude, unabated losses are between 2-10%. While all adaptation measures are technically effective, only a few are cost effective. Hence, only the earth-air heat exchanger (EAHE) and changes in ventilation rate (VENT) are chosen by the model. Additional benefits of the measures are decisive (e.g. heating in winter) with high uncertainties resulting from bio-physical processes. Furthermore, we did not test combined adaptation measures and variation in adaptation costs, which should be part of sensitivity analyses.

The direction depending separation distances have been calculated for the two sites, the two stability schemes and for the present and future climate (WP 2). They have been calculated for two odour impact criteria according to GOAA (2008), namely for a threshold of $1 \text{ ou}_E \text{ m}^{-3}$ and exceedance probabilities of 10% for pure residential areas and 15% for commercial/industrial and agriculturally dominated areas.

The separation distances are shown as isopleths of the OIC in Fig. 14, encompassing the area of exceedance of the given thresholds. An increase in (tolerated) exceedance probability reduces the affected area; a limit value of 15 % (Fig. 14b) is thus more unfavourable for residents than a limit value of 10 % (a higher level of protection, Fig. 14a). The black rectangle in the middle of both charts in Fig. 14 is the livestock building. The area displayed is $1000 \times 1000 \text{ m}$, with the odour source in the centre. The bold lines depict separation distances obtained by the method based on the cloudiness, the thin lines those by the method based on the radiation balance. Separation distances at Wels are shown in red, those at Feldbach in blue.

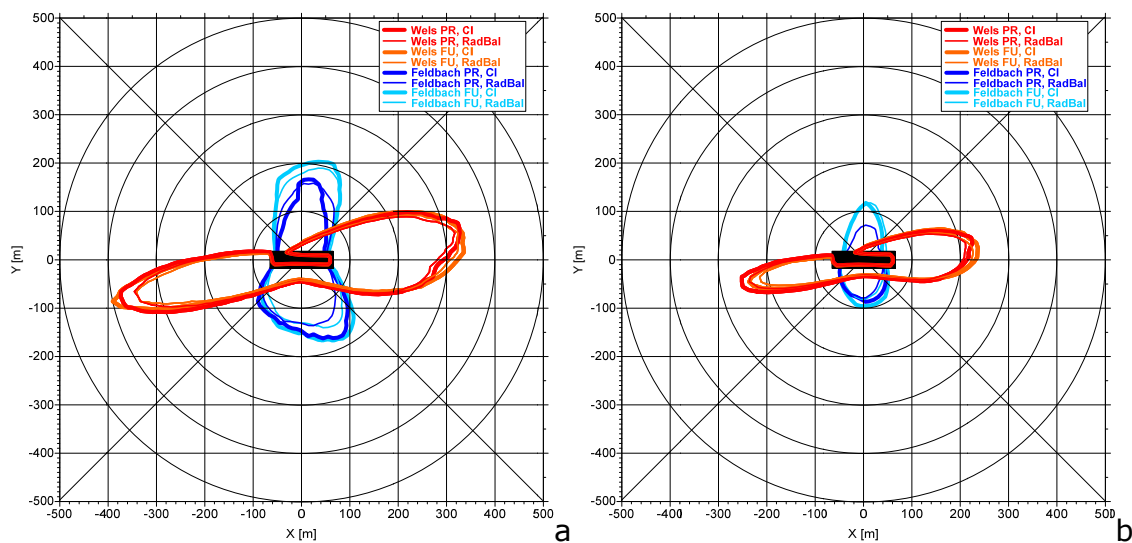


Fig. 14: : Direction-dependent separation distances (m) for (a) 10% exceedance probability (pure residential areas) and for (b) 15% exceedance probability (commercial/industrial and agriculturally dominated areas) at Feldbach and Wels, both for PR (present climate (1981-2010)) and FU (future climate (2036-2065)); based on a combination of cloudiness and wind speed (CI) and of radiation balance and wind speed (RadBal) to determine stability classes; the black rectangle is the livestock building.

Because of the higher wind speeds and the predominantly neutral stability conditions with the highest peak-to-mean ratios, the maximum separation distances at Wels are more than two times larger than at Feldbach (Fig. 14a and Fig. 14b). Separation distances have been calculated for the same livestock unit, at both sites. The changes in separation distances between the present and the future climate can be explained directly by the changes in the meteorological conditions: there is a tendency that maximum separation distances will slightly increase in Feldbach, due to the increase in wind speed and neutral stability classes; there is a mixed result for Wels and only small changes, but the maximum separation distances towards South-west will be reduced in the future, especially for an exceedance probability of 10 % for residential areas (Fig. 14a). The most significant changes occur for the cloudiness method at Feldbach. If 15 % are tolerated, no separation distance north of the livestock unit can be determined in the present climate. In the future scenario, a maximum separation distance of about 100 m towards north is obtained.

5 Schlussfolgerungen und Empfehlungen

Heat stress for intensive pig and poultry production will increase in the future due to climate change. Even in temperate climates such as in Central Europe, this will cause economic losses for farmers. To reduce heat stress for farm animals, three energy saving air treatment devices were investigated. The evaluation of the performance was done by parameters which are used to describe heat stress for pig and poultry.

Earth-air heat exchangers show the best performance. By the use of this system, heat stress can be totally avoided. Beside the cooling effect, the following benefits can be expected: (1) effective damping of short-term temperature fluctuations, and (2) heating of the inlet air temperature during wintertime which increases the ventilation flow rate and the related indoor air quality.

Direct evaporative cooling by cooling pads shows a high potential for reducing temperature, depending on the relative humidity of the outdoor air. Due to the adiabatic cooling, the inlet air humidity ranges between 75% and 100%, which can cause problems inside the livestock buildings by moistening bedding materials.

Indirect evaporative cooling by cooling pads in combination with a subsequent heat exchanger results in a reduction of the inlet air temperature by evaporation without humidification. The additional feature is the possible use of the heat exchanger during wintertime, to reduce the sensible heat loss of the livestock building by heating the outside air by means of the outlet air of the livestock building.

The simulation of the indoor climate of confined livestock buildings shows a lower resilience for global warming compared to the outside situation. The mean relative annual trend for heat stress parameters between 1981 and 2017 lies in the range between 0.9 and 6.4% per year, relative to the year 1981. The more frequently and more distinctly occurring heat stress situations have an essential influence on the performance, health and welfare status of livestock. Future impacts of global warming will be even more severe. To reduce animal health and welfare problems as well as the economic impact of these changes, appropriate adaptation measures are needed. The selection has to focus on adaptation measures with low investment and operating costs. Long-term (seasonal) climate forecasts similar to those offered for crop producers would be essential for decision-making tools aiming at mitigating heat stress for livestock inside confined buildings. The calculations for growing-fattening pigs show that such a simulation model for the indoor climate of confined livestock buildings is an appropriate tool to determine conditions of heat stress for livestock.

Global warming negatively impacted livestock keeping in confined buildings during the last three decades will do so in the future according to the trend analysis in this study. Robust measures of heat stress inside the livestock buildings can only be quantified by a simulation model of the indoor climate over

longer time periods. Compared to the outdoor raised farm animals, the indoor situation shows a lower resilience. By the use of adaptation measures heat stress can be reduced and resilience increased. Especially energy saving air preparation devices can reduce heat stress in the range between 60 and 100%. Other adaptation measures like the reduction of the stocking density and the shift of the activity pattern of the animals to night-time are less effective.

The results show clearly that already existing cooling technologies can be applied in confined livestock buildings to successfully reduce heat stress for farm animals in Central Europe. Nevertheless, economic evaluations are necessary to prove whether the biometeorological effects of the suggested devices in limiting livestock production losses justify additional investment and maintenance costs. Such assessments would require to link the models in this study with climate change scenarios and economic farm models.

According to the results from FAMOS space, climate trends lead to adaptation pressure to maintain livestock productivity and welfare. The cost-effectiveness of adaptation measures strongly depends on cost assumptions and assumptions of bio-physical processes, which both appear uncertain. The most cost-effective but long term and costly adaptation measures such as EAHE – we assumed a depreciation period of 30 years - can be considered as a risky investment in times of unclear future market developments and constrain farm adaptation measures.

Local meteorology exerts a profound impact on a site-specific quantity like the separation distance to protect the neighbourhood from odour annoyance. Because of the relatively complex interaction of the meteorological parameters and the peak-to-mean factors when determining separation distances for given exceedance probabilities, no a priori forecast is possible. In a region of interest, separation distances will increase or decrease in a future climate scenario. A decrease will certainly lead to a relief for planning and zoning purposes. If the outcome of such an investigation is an increase like in Feldbach, practice will show in the future which increases will be tolerated and which will cause technical or legal efforts to overcome these unwanted changes. Due to the durability of today's investment decisions for new livestock facilities, location-sensitive results as presented in this study can be valuable tools for land use planning and zoning.

C) Projektdetails

6 Methodik

The production of pig meat and poultry is severely affected by heat stress. Recent publications in farmer magazines show the importance even for Austria today. For the US the economic loss for poultry (broilers, laying hens, and turkeys) are in the range between 130 to 170 10^6 US\$ per year, for pigs about 300 10^6 US\$ per year (St-Pierre et al., 2003). In temperate climate regions like Middle Europe these animals are predominantly kept in confined housing systems (APCC, 2014; Integrated Pollution Prevention and Control (IPPC), 2003), which are the source of much of the world's poultry and pig meat production (Thornton, 2010).

There are only few investigations of the impact of climate change on confined livestock houses. Most of the studies are dealing with ruminants kept on grassland and the emission of greenhouse gases. The effect of climate change on intensive livestock was not in the focus of interest (e.g. AnimalChange, EU-FP7 <http://www.animalchange.eu/>). In many cases confined livestock keeping is not seen as vulnerable to climate change (e.g. Skuras and Psaltopoulos, 2012), because the indoor climate is controlled to some degree. This assumption is only valid for a temperature range close to the thermoneutral zone, where the ventilation flow rate can be controlled.

The requirements of pigs (fattening and breeding) and poultry (broilers, laying hens, turkeys) for their thermal environment depend on the age and physiological stage of the animals. The younger the animals, the higher the target temperature. For livestock in temperate climate zones this means that these animals have to be kept in warm confinement houses (Gillespie and Flanders, 2009). A mechanical ventilation system is an essential part of a warm confinement building (Integrated Pollution Prevention and Control (IPPC), 2003). Such a livestock building is one that is closed, insulated and operated in a way that keeps inside temperatures higher than, and independent of, outside temperatures during winter months. During summertime such confined housing systems can only be ventilated with a maximum ventilation rate to reduce the exceedance of the indoor temperature over the outside temperature to a certain extent of about 2 to 4 K. This means that the indoor climate can be controlled only marginally.

The indoor climate in confined livestock systems is a result of the interaction between the animals, which releases sensible and latent (water vapour) heat, the insulation of the building to capture the sensible heat, and the ventilation system. The ventilation rate is mostly controlled by the indoor temperature. The ventilation system is the most effective link to the outside, but inevitably differences will occur between climatic conditions outside and inside livestock buildings. This means that the outside meteorological situation alone cannot be

used to evaluate the thermal environment of the animals. The modified indoor climate is then the relevant environment for the farm animals.

The empirical investigation is planned for two areas in Austria with a high density of animal husbandry and different climatic conditions, namely the Northern Alpine Foreland in the provinces Upper Austria/Lower Austria and South-Eastern Styria. These two regions cover more than 90% of all pigs in Austria and about two thirds of poultry (Statistik Austria, 2013).

For these two regions a reference scenario will be compiled on the basis of representative observational sites, available for the time period 1981-2010 with a time resolution of one hour. The future scenario will be generated for 2036–2065. This time period was selected according to the life expectancy of livestock housings in the range of about 30 to 50 years.

The simulation of the indoor climate (thermal parameters and air quality) for the confined livestock houses for poultry and pigs will be driven by the meteorological parameters, using the reference (1981-2010) and future (2036-2065) datasets. The system parameters for a certain livestock house will be the same for both of the two datasets, called Business-as-Usual. These model parameters depict a typical confined livestock building with a mechanical ventilation system as it is used for different livestock keeping systems (broilers, laying hens, turkeys, and various pig keeping systems). The simulated parameters of the indoor climate will be analysed and compared for the two datasets, taking into account animal welfare, health, performance, the environmental impacts, and the resulting economic consequences. It results in an assessment of the **potential impact** of climate change on typical confined pig and poultry buildings.

In a next step the husbandry conditions will be adapted to reduce unwanted effects of the climate change scenarios like evaporative cooling and reduction of animal density. The resulting modification of the simulation reveals the **effectiveness of adaptation measures (i.e. adaptive capacity)**, which sums up to **livestock and farm vulnerability** (e.g. Klein et al., 2014). Even if some of the adaptation measures are well known especially in hot climate regions such as in parts of the US, it has to be evaluated whether they will be appropriate for Austrian farmers due do different farm structure, markets, production regulations or climate change impacts. The evaluation will include the direct bio-physical effects on animals and the environment as well as their economic implications, i.e. impacts on production costs and revenues.

The sketch in Fig. 15 gives an overview over the work flow to assess the vulnerability of conventional confined livestock buildings to climate change scenarios and the effectiveness of adaptation measures. Both criteria are evaluated by aspects of animal health, welfare, performance, environmental impacts and the resulting economic consequences.

The outcome of these model calculations will help to evaluate adaptation measures, which are under discussion (e.g. wallow for pigs), on a scientific basis. Due to the long-term investment of livestock buildings, it is important to consider necessary features in the planning of new livestock buildings for future challenges due to climate change.

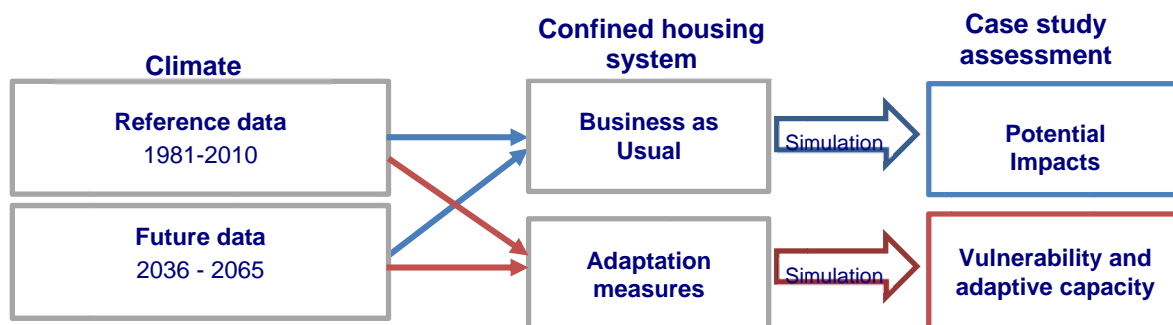


Fig. 15 Structure of the Project *PIPoCool*

7 Arbeits- und Zeitplan

The major goals of the project could be fulfilled starting from the meteorological data, the simulation of the indoor climate, the simulation of adaptation measures, the economic impact and the impact on airborne emissions. For fattening pigs the entire steps could be published in high-ranked journals and presented at international congresses. In Annex 2.5 the list shows 11 papers which were published, in press, or at least submitted. Five of these are published in high-ranked peer reviewed journals (Biosystems Engineering (2x), Int. J Biometeorology, Climatic Change, Chemical Engineering Transactions). All of these papers are open-access available, according to the funding terms.

The consortium decided to work in depth in the field of pigs and to omit poultry. Otherwise the scientific standard could not be reached neither for pigs nor for poultry.

8 Publikationen und Disseminierungsaktivitäten

The project results deliver essential information on the future perspectives of livestock husbandry under global warming. The scientific papers were or will be published in peer reviewed open access journals. The list of papers is given in 2.5 Annex of this report. Beside these publications, the results were also presented at the following scientific congresses:

- (1) 67th Annual Meeting of the European Federation of Animal Science Belfast UK, 29 Aug – 2 Sept 2016
- (2) International Congress of Biometeorology ICB 2017, Durham University, Durham, UK
- (3) Klimatag 2017, Vienna
- (4) International Symposium on Animal Environment and Welfare, Rongchang, Changqing, China
- (5) 6th International Conference on Environmental Odour Monitoring & Control. NOSE'18 September 9-12, 2018 in Milan, Italy
- (6) 9. BIOMET-Tagung 28.11. - 30.11.2017, Stralsund
- (7) 28th Annual Conference of the Austrian Society of Agricultural Economics (ÖGA), 27.-28.9. 2018, Vienna

The Website of the project is hosted at the University of Veterinary Medicine (www.vetmeduni.ac.at/pipocool). Besides the scientific papers also the press release of the University of Veterinary Medicine and all reports in newspapers are presented there. For a new issue of *ACRP in essence*, *Agriculture II*, the PiPoCool project was presented. A fact sheet with the title *Klimawandel, Auswirkungen auf die Landwirtschaft. Die Haltung landwirtschaftlicher Nutztiere in Stallungen* is submitted to the CCCA and in the review process.

To broaden the dissemination to farmers, agricultural experts, consultants and well established organisations were contacted. There we showed our willing and interest to present the project results. In this respect it is planned to present the results of the project at the following events: Wintertagung (an event with special sessions for livestock farmers), ÖKL Seminars (organised by a well established organisation for education and training of farmers), Landwirtschaftskammer Österreich (Austrian Chamber of Agriculture). In cooperation with the Austrian Chamber of Veterinarians and the Tiergesundheitsdienst TGD (animal health service), also all veterinarians, working in the field of farm animals, are part of the dissemination process. Furthermore, final results will be published in a farmer magazine.

Scientific Publications

- (A) Schauburger G., Vitt R. (2017) Impact assessment of climate change on intensive pig and poultry production by the simulation of the indoor climate of livestock buildings. 21st International Congress of Biometeorology ICB 2017, Durham University, Durham, United Kingdom p 61
- (B) Vitt R., Weber L., Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Schauburger G. (2017) Modelled performance of energy saving air treatment devices to mitigate heat stress for confined livestock buildings in Central Europe. Biosystems Engineering, 164, 85-97.
- (C) Vitt R., Weber L., Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Schauburger G. (2017) Mitigation of Heat Stress by Energy Saving Air Treatment Devices for Confined Livestock Buildings. In: Ni, J.-Q., Lim, T.-T., Wang, C., Zhao, L. (Eds.), Animal Environment and Welfare. China Agriculture Press, Beijing, China, p 127 – 134.
- (D) Mikovits Ch., Ronja Vitt R., Schauburger G. (2017) Simulation of the indoor climate of livestock buildings to assess of adaptive measures to reduce heat stress due to climate change. In: Ni, J.-Q., Lim, T.-T., Wang, C., Zhao, L. (Eds.), Animal Environment and Welfare. China Agriculture Press, Beijing, China, p 67-74.
- (E) Schauburger G, Piringer M, Mikovits C, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Impact of global warming on the odour and ammonia emissions of livestock buildings used for fattening pigs Biosystems Engineering. 175 (2018) 106-114
- (F) Schauburger G, Piringer M, Mikovits C, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Temporal Trend of Odour Emission of Livestock Buildings for Fattening Pigs due to Climate Change. Chemical Engineering Transactions. 68 (2018) 121-126. DOI:10.3303/CET1868021
- (G) Mikovits Ch., Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Schauburger G.: Impacts of global warming on confined livestock systems for growing-fattening pigs: simulation of heat stress for 1981 to 2017 in Central Europe Int. Journal of Biometeorology, 63 (2019) 221–230 DOI: [10.1007/s00484-018-01655-0](https://doi.org/10.1007/s00484-018-01655-0)
- (H) Schauburger G, Mikovits C, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Knauder, W., Anders I., Andre K., Hennig-Pauka I., Schönhart M. PiPoCool - Der Einfluss globaler Erwärmung auf die Tierhaltung in Stallungen. ACRP in Essence Landwirtschaft II 2019.
- (I) Schauburger G, Mikovits C, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Knauder W., Anders I., Andre K., Hennig-Pauka I., Schönhart M. Global warming impact on confined livestock buildings: efficacy of adaptation measures to reduce heat stress for growing-fattening pigs. Climatic Change, in revision
- (J) Piringer M, Knauder W., Anders I., Andre K., Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Hennig-Pauka I., Schönhart M. Schauburger G, (2019) Climate change impact on the dispersion of airborne emissions and the resulting separation distances to avoid odour annoyance. Atmospheric Environment X, 2, 100021, DOI: [10.1016/j.aeaoa.2019.100021](https://doi.org/10.1016/j.aeaoa.2019.100021)
- (K) Schauburger, G., Zollitsch, W., Hörtenhuber, S.J., Baumgartner, J., Niebuhr, K., Piringer, M., Knauder, W., Anders, I., Andre, K., Hennig-Pauka, I., Schönhart, M., 2019. Klimawandel: Auswirkungen auf die Landwirtschaft. Die Haltung landwirtschaftlicher Nutztiere in Stallungen, [CCCA Fact Sheet #26](#). Climate Change Centre Austria, Graz.

Publications in preparation

- (a) Schauburger G, Zollitsch W., Hörtenhuber St. J., Baumgartner J., Niebuhr K., Piringer M., Knauder, W., Anders I., Hennig-Pauka I., Schönhart M. Adaptation measures to abate heat stress inside confined livestock buildings – a review. Biosystems Engineering, in preparation
- (b) Weber, L. Three energy saving cooling devices for warm confined livestock buildings to mitigate heat stress in Central Europe, Master Thesis, University of Veterinary Medicine Vienna, in preparation
- (c) Hörtenhuber St. J., Schönhart M., Mikovits Ch., Zollitsch W., Baumgartner J., Niebuhr K., Piringer M., Knauder, W., Anders I., Andre K., Hennig-Pauka I., Schauburger G. Temperature increases and effects on the performance of livestock as well as on environmental indicators – The examples of pig and poultry in confined housing systems in Austria. in preparation
- (d) Schönhart, M., Schmid, E., Mikovits, C., Hörtenhuber, S.J., Zollitsch, W., Baumgartner, J., Niebuhr, K., Piringer, M., Anders, I., Andre, K., Hennig-Pauka, I., Schauburger, G. Cost-effective adaptation strategies to reduce heat stress of growing-fattening pigs under climate change. In preparation.

Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte sowie die barrierefreie Gestaltung der Projektbeschreibung, übernimmt der Klima- und Energiefonds keine Haftung.

Die Fördernehmerin/der Fördernehmer erklärt mit Übermittlung der Projektbeschreibung ausdrücklich über die Rechte am bereitgestellten Bildmaterial frei zu verfügen und dem Klima- und Energiefonds das unentgeltliche, nicht exklusive, zeitlich und örtlich unbeschränkte sowie unwiderrufliche Recht einräumen zu können, das Bildmaterial auf jede bekannte und zukünftig bekanntwerdende Verwertungsart zu nutzen. Für den Fall einer Inanspruchnahme des Klima- und Energiefonds durch Dritte, die die Rechteinhaberschaft am Bildmaterial behaupten, verpflichtet sich die Fördernehmerin/der Fördernehmer den Klima- und Energiefonds vollumfänglich schad- und klaglos zu halten.