Animal Production Systems group

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The effect of temperature and activity patterns on lying behaviour and space use in conventional housed fattening pigs

An Agent-Based Approach

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Abstract

Lying behaviour is an important thermoregulatory behaviour in pigs. Pigs can adapt to changing temperatures by changing lying time, lying location, huddling and lying posture. Activity patterns of pigs, with one or two activity peaks, are expected to influence these lying behaviours and thereby space requirements of conventionally housed fattening pigs. The aim of this study was to gain more insight in the effect of ambient temperature and activity patterns of pigs on space use and finding preferred lying places in a pen. A literature study was performed to identify the key factors affecting the four aspects of lying behaviour (lying time, location, posture and huddling), the relation between lying behaviour and space use, and the effect of ambient temperature and activity patterns of pigs. Based on this information an Agent-Based Model on lying behaviour and space use of pigs during 24 h was developed. This model represented a conventional pig housing pen with 10 fattening pigs. The effect of different temperatures within the thermoneutral zone, in the cold zone (10 ˚C), the comfort zone (18 ˚C, 19 ˚C and 20 ˚C) and in the warm zone (30 ˚C), on lying behaviour and space use was tested. Additionally, the effect of activity patterns with one and two activity peaks was tested. Model results show that increasing temperature, increased floor occupation and increased the difficulty for pigs to find a preferred lying place. The amount of activity peaks had no effect on floor occupation. The amount of pigs that had difficulties with finding a lying place in the preferred area near the wall, however, differed for the two types of activity peaks. Pigs with one activity peak had more often difficulties with finding a lying place in the preferred area. Increasing temperature also causes more difficulties with finding a preferred lying place. These results indicate that activity patterns of pigs can be an important factor affecting space requirements of pigs, especially at higher temperatures.

Contents

1. Introduction

In conventional pig housing systems, pigs spend about 86 percent of their time lying (Huynh et al., 2005). Lying behaviour can be defined as lying down, having no active contact with other pigs (Barnett et al., 1985) and, therefore, includes both resting and sleeping behaviour. Throughout the day, the amount of lying behaviour changes. Most pigs have one or two activity peaks and during daytime the overall lying time is lower than during the night (Ekkel et al., 2003; Gonyou et al., 1992).

Pigs have to maintain a constant internal body temperature and, therefore, they produce metabolic heat. The heat that is left over, has to be transmitted to the environment. This process of producing and transmission of heat is called thermoregulation (Kanis et al., 2004). Lying behaviour has an important factor in thermoregulation in pigs, since pigs cannot sweat (Ingram, 1965) and rely on various behavioural changes to loose and retain heat. Therefore, preferences in lying behaviour change when ambient temperature changes (Huynh et al., 2005). Different zones in thermoregulation are shown in figure 1. If the metabolic heat production is not affected by the ambient temperature, pigs are in their thermoneutral zone, which includes both the comfort zone and the warm and cool zone (Atrian et al., 2012). In the thermoneutral zone, pigs can easily adapt to the ambient temperature to maintain their body temperature by vasoconstriction and vasodilatation (Kanis et al., 2004). In the cold zone, pigs have to take more extreme physiological actions to maintain their body temperature (Mount, 1979). Pigs in the cool zone are likely to huddle and increase activity. When pigs are in the cold zone, they will search for more extreme behaviours to increase heat production and will for example shiver. If the temperature reaches the Lower Critical Value (LCV) pigs will suffer from cold stress and body temperature decreases. When temperature rises above the comfort zone and reaches the warm zone, pigs will decrease activity and change their lying posture (Kanis et al., 2004). Pigs in the hot zone will try to increase heat loss even more and will, therefore, reduce feed intake, wallow themselves in their excretions and start panting to increase heat loss (Kanis et al., 2004). An ambient temperature that is too high to cope with, above the Upper Critical Value (UCV), will cause heat stress and may cause an increase in body temperature. Long periods with an ambient temperature below the LCV or above the UCV can ultimately lead to death (Kanis et al., 2004).

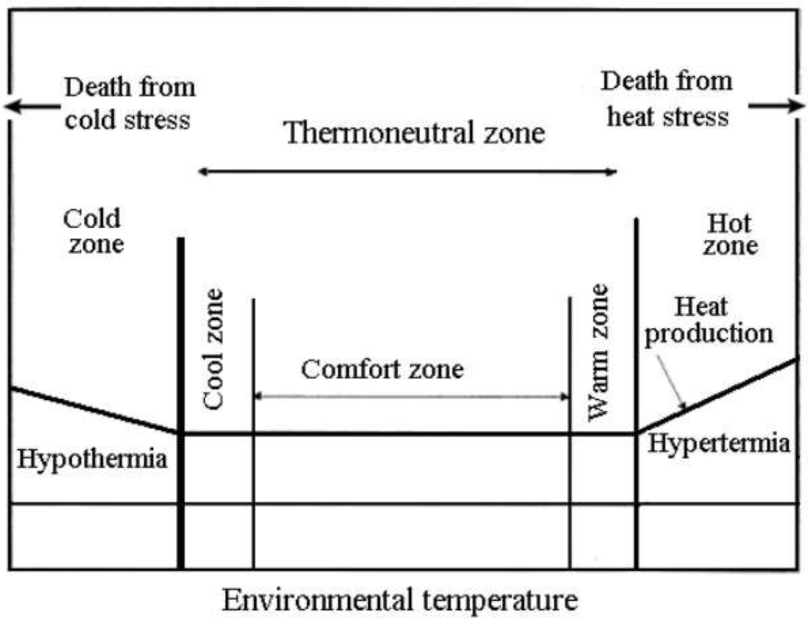


Figure 1. Schematic overview of the thermoneutral and comfort zone (Atrian et al., 2012).

Pigs have preferences on lying behaviour which involve aspects such as lying time, lying location, posture and huddling. When the ambient temperature is within the comfort zone, pigs have a preference for a soft, dry and clean location to rest and will try to avoid soiled surfaces (Spinka, 2009). Thereby, pigs prefer to huddle and mostly lie in a lateral posture (Huynh et al., 2005). Changing ambient temperature will cause an overall change in the amount of activity and huddling in pigs (e.g. Huynh et al., 2012; Pedersen et al., 2003; Aarnink et al., 2006). Thereby, lying posture and location will also change: an increase in ambient temperature, for example, is accompanied with an increase in lateral lying (Huynh et al., 2005; Aarnink et al., 2006) and preference for lying location shifts from the solid floor area towards the slatted floor area (Huynh et al., 2005).

When pigs change their lying behaviour, this can affect space use (Spoolder et al., 2012). A change in posture, can be accompanied with a change in space occupation and huddling pigs, thereby, occupy less space than pigs lying individually. Active pigs occupy less space than pigs in lateral or half-lateral posture and, therefore, a decrease in activity is often accompanied with an increase in space occupation. The activity pattern with activity peaks also has an effect on lying behaviour and, therefore, the use of space differs during the day. The activity pattern in pigs involves the fluctuating chance pigs will lie during 24 hours, with lying peaks and activity peaks. Even though there might be a major effect, it is still unknown how activity patterns with one and two activity peaks affect lying behaviour and space use of conventionally housed pigs, and how this is influenced by temperature. This study, therefore, will focus on the influence of lying behaviour on floor occupation under different ambient temperatures within the thermoneutral zone with different activity patterns by building an Agent-Based Model (ABM). An ABM can be used to study the effect and include interactions among pigs and with their environment. Results of this study can be used to optimise thermoregulatory behaviour in pigs, since the most optimal combination of temperature and activity pattern can be implemented in a pig housing system.

2. Materials and Methods

To gain insight in the effects of temperature and activity patterns on lying behaviour and space use, a literature study was done. In this literature study, the effects of lying behaviour and temperature on space use and the possibilities for finding a lying place were explored. The information from the literature study served as input for the simulation model.

A simulation model was built with the results from the literature study. The simulation model was made through Agent Based Modelling. With Agent Based Modelling it is possible to study the effect of actions and interactions of individual pigs on each other and on the system as a whole. The model represented a pig housing system with ten pigs and their lying behaviour. The model was implemented in the software programme Netlogo 5.1.0. With Netlogo it is possible to model a purposeful and simplified representation of complex systems (Railsback & Grimm, 2011) in which the pigs were modelled as agents with pre-programmed characteristics and rules. The pigs in the model were able to interact with each other and their environment.

A sensitivity analysis was conducted to determine the effect of different parameters used in the model on model output. This analysis was performed by varying one parameter at the time, keeping all other parameters constant. The parameters that were tested were set at the standard setting in the model and an increase and decrease of 50 percent of the standard settings.

The model ran to obtain results to answer the research question. Two factors were altered during all runs: temperature and amount of activity peaks. Temperatures in several ranges were chosen: the border of the cool zone and the border of the warm zone. For pigs of 62 kilograms, 10 degrees Celsius was found as the lower border of the cool zone by Mangold, 1965. Mount (1967) found that 30 degrees Celsius is the upper border of the warm zone. Temperatures in the thermoneutral zone were thereby chosen to study changes in lying behaviour and space use. Verstegen (1970) found that the thermoneutral zone for group-housed fattening pigs of 60 – 70 kilograms is between 16 and 23 degrees Celsius. The model was tested at temperatures of 18, 19 and 20 degrees Celsius, since these temperatures lie within the thermo comfort zone and the inflection point for the shift in preference for floor type (Huynh et al., 2005). The normal pen size for conventional housed fattening pigs of 60 kilograms is about 1 m^2 per pig (Dierenbescherming, 2015). Therefore, the pen length was set at 5 meters and pen width was set at 2 meters, which results in a pen of 10 m^2 for a group of 10 pigs. Since lying pattern might influence the results, both activity patterns, with one activity peak and with two activity peaks, were analysed. In total the model ran for 10 different settings and 1000 times for each setting. After each run, the final values were measured and the average of these values was analysed. To gain insight in the development of the pattern for floor occupation over the day for the two activity patterns within the thermoneutral zone, the model ran for 30 times with the temperature set at 20, for both activity patterns. Every time step, all results were reported and the average per time step was calculated to be able to make a graph with the development of floor occupation over the day. Next to the development of the pattern for floor occupation, the development of the amount of pigs that could not lie in their preferred area was measured. Settings for this test were equal to the settings for measuring the development of floor occupation. Results were measured each time step and means per time step were calculated.

3. Theoretical background

As ambient temperature influences lying behaviour and, therefore, space use, this chapter will explore the various aspects of lying behaviour and space use. This chapter will thereby explore what the effect of temperature and amount of activity peaks on lying behaviour and space use is.

3.1 Lying behaviour and the effect of temperature

Lying behaviour can help pigs to maintain thermo comfort, because of its influence on body temperature. When the ambient temperature is high, pigs will focus on cooling down and increase heat loss. When temperature is low, pigs will try to warm up and decrease heat loss. Four aspects of lying behaviour are most important in maintaining thermo comfort: huddling, the amount of lying, lying posture and lying location (Huynh et al., 2005).

3.1.1 Amount of lying behaviour

Pigs spend 93 percent lying time during the night and are more active during the day, bringing the average percent of their time lying at 86 percent in a thermoneutral environment (Huynh et al., 2005; Ekkel et al., 2003). The amount of lying time varies among different temperatures and among studies. There is, however, a positive linear relation shown between temperature and lying time (Table 1). This shows that an increase in temperature is related to an increase in lying time. The amount with which this lying time differs is probably related to the body weight. The percentage lying pigs is fluctuating during day. Pigs have a diurnal rhythm with peaks in activity as described by Van Putten (2000) and Ekkel et al. (2003). Ekkel et al. (2003) found a lying pattern with two activity peaks, shown in figure 2. Gonyou et al. (1992), however, looked into the time spent lying and found one activity peak per day, as can be seen in figure 3. This difference in lying pattern can possibly be explained by the difference in illumination: the pens in the study of Gonyou et al. (1992) were constantly illuminated and the lights in the study of Ekkel et al. (2003) were switched off during the night, which might influence lying patterns (Van Putten & Elshof, 1983).

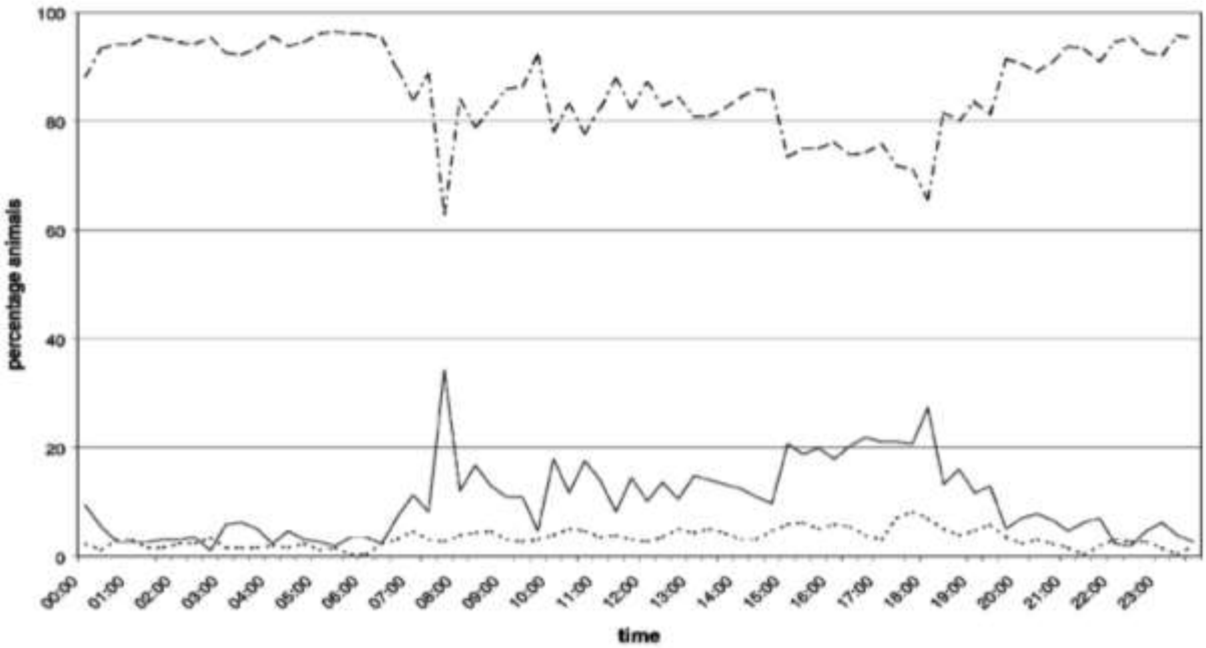


Figure 2. Lying pattern with two activity peaks, found by Ekkel et al. (2003). The upper line, with stripes and dots, represents lying, the solid line represents standing and the lower dotted line represents sitting.

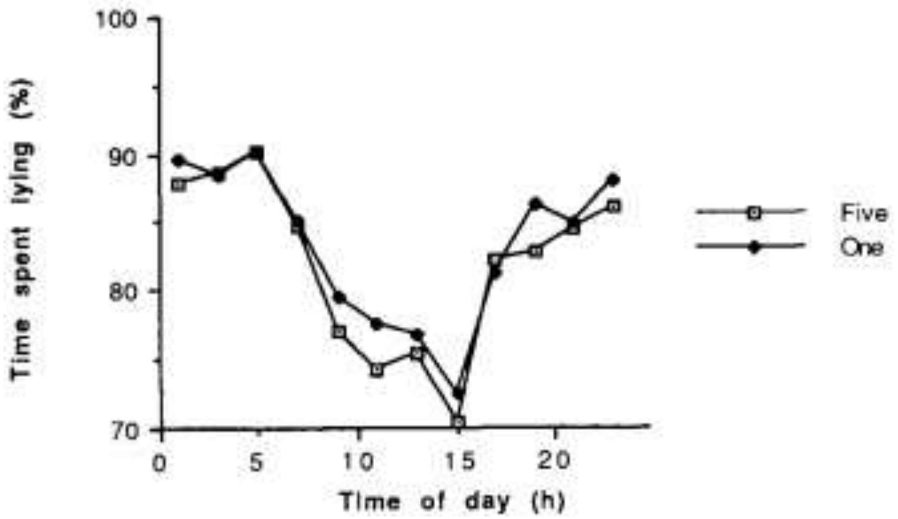


Figure 3. Lying pattern during the day for conventional housed fattening pigs, housed individually or in groups of five, found by Gonyou et al. (1992).

3.1.2 Lying location

Pigs have a preference for a specific lying location. Pigs prefer to rest on a soft and dry floor (Blackshaw, 1980; Spinka, 2009). From nature, pigs are clean animals and willing to separate the dunging area from the lying area (Aarnink, 1997), therefore, if pigs rest in the solid floor area, they urinate and defecate in the slatted floor area (Aarnink et al., 1996). At high temperatures, however, pigs prefer to rest on the slatted floor which is cooler than the solid floor, because more skin area has contact with the air. The functional areas that was used as dunging area and lying area become multi-functional areas: pigs start dunging and lying in both areas (Spoolder et al., 2012). The inflection point of this shift in preference for pigs of 65 kilograms is 19 degrees, which is exactly in the middle of the thermo comfort zone. Below this temperature, pigs only lie on the solid floor. Above 19 degrees, pigs preference shifts towards the slatted floor (Huynh et al., 2005). If the pen has a wall around it, pigs choose this wall to lie against. When no wall is available, they can use the feeding trough as substitute wall (Blackshaw, 1980).

3.1.3 Huddling

Next to lying against the wall, pigs prefer to huddle. Huddling can be defined as ‘an active and close aggregation of animals’ and is a cooperative group behaviour in social thermoregulation, permitting individuals involved to minimise heat loss and thereby lower energy costs (Alberts, 1978; Gilbert et al., 2010). Huynh et al. (2005) defined huddling as ‘pigs lying with over 50 percent of their lying side in contact with another lying pig’. Pigs with a body weight below 50 kilograms sometimes entirely lie on top of each other. Pigs with a bodyweight above 50 kilograms, however, show none of this behaviour, probably because it is uncomfortable for a pig to support a heavy pig on top of it (Boon, 1982a). Huynh et al. (2005) found that pigs with a bodyweight of 62 kilograms huddle 36.3 percent of their lying time at an ambient temperature of 24 ˚C. Pigs in the cool or cold zone can use huddling to decrease body heat loss (Kanis et al., 2004; Spoolder et al., 2012). When the temperature is above the cool zone, the amount of huddling against pen mates decreases. The percentage by which the amount of huddling decreases differs among different studies. Although there is a difference in amount of decrease in huddling that both studies found, a negative linear relation between temperature and huddling is shown by both studies (Table 1).

3.1.4 Lying posture

Pigs can rest in three different postures. One of these postures is lateral: lying on one side, not supported by legs at all. Pigs in this posture make as much contact with the floor as possible and this posture, therefore, is useful to cool down. Pigs can also lie sternal: lying on the belly, supported by three or four legs. Pigs in this posture make less contact with the floor than pigs in a lateral posture and, therefore, this position is more used in cool environments. A posture that is intermediate between lateral and sternal posture, is the half lateral posture. In this posture, a pig lies, while supporting its body with one or two legs (Huynh et al., 2005). Huynh et al. (2005) found that pigs with a bodyweight of 62 kilograms and an ambient temperature that varied between 16 and 32 ˚C on average lied 12.4 percent in sternal posture, 15.4 percent in half lateral posture and 72.2 in lateral posture. Literature does give different results to what extent the pigs change lying posture with changing ambient temperature. A linear increase in lateral lying posture with an increase in temperature, however, is found by all studies (Table 1).

Table 1. The effect per degree Celsius increase on huddling, the amount of lying and lying in lateral posture, found by Huynh et al. (2005), Aarnink et al. (2006) and Pedersen et al. (2003)

Reference	Huddling	Amount	Lying in lateral posture	Temperature range (˚C)
Huynh et al. (2005)[a]	-4.90%	0.20%	0.80%	16 - 32
Aarnink et al. (2006)[b]	-3.70%	0.50%	1.40%	18 - 28
Pedersen et al. (2003)[c]	-1.70%	0.66%	1.90%	10 - 28

a. Pigs of about 62 kg body weight. b. Pigs of 25 up to 105 kg body weight. c. Pigs of 60 up to 110 kg body weight

3.2 Space use

With a change in ambient temperature, a shift in preferences on lying behaviour is accompanied and, therefore, the space that pigs use also changes (Spoolder et al., 2012). Group housed pigs use space for three purposes: (1) the space that the body of the pig occupies or 'static space', (2) the space needed to perform different behaviours, like feeding and excretion, or 'activity space' and (3) space for appropriate social behaviour or 'social space' (Petherick, 1983).

For static space it is relatively easy to make an estimation of the space occupation for a single pig, which depends on body posture and weight. Petherick and Baxter (1981) found that pigs in a lateral lying position occupy 0.047 m^2 per kilogram $bodyweight^{2/3}$, in a half lateral lying position 0.033 m^2 per kilogram $bodyweight^{2/3}$ and in a sternal lying posture 0.019 m^2 per kilogram $bodyweight^{2/3}$. This means that, for example, a pig with a bodyweight of 62 kilograms in a lateral posture will occupy a space of $0.047 \times 62^{2/3} = 0.74$ m^2, $0.033 \times 62^{2/3} = 0.52$ m^2 in a half lateral position and $0.019 \times 62^{2/3} = 0.30$ m^2 in a sternal posture. The amount of space that a standing or sitting pig occupies, is equal to the space occupation of a pig in sternal lying position (Petherick and Baxter, 1981).

The activity space is, in comparison to static space, more difficult to quantify. Studies that aim to determine the activity space, often use overhead pictures to determine the amount of space needed (e.g. Bogner et al., 1979; Freeman, 1983). When pigs are involved in moving activities, like running, activity space use increases, for example to be able to avoid other pigs or the walls. Parts of the pen that are used for different purposes, or functional areas, have to be taken into account and the amount of space that is needed per pig must be considered for each area. Some functional areas overlap and are a multi-functional area, for example if feeding systems are placed in the lying area, the feeding area and lying area overlap (EFSA, 2005).

The social space of a pig is the most difficult to quantify. Social space depends on the personal space, for example the space that is needed to avoid constant physical contact. Thereby, the space that is needed to engage in social interactions, for example fighting or mounting, is also defined as social space (Spoolder et al., 2012). No studies have quantified the amount of space that is needed to perform social behaviour.

4. Model description

An ABM was built in Netlogo to simulate pigs in a conventional housing system. This chapter will explain the agents, environment and processes in the model.

4.1 The interface of the model

Figure 4 shows the visual representation of the model: one pen with a group of conventional housed pigs. The pen was divided into a slatted and a solid floor. The slatted floor occupied 40 percent of the floor (grey area in Figure 4). The solid floor occupied 60 percent of the floor (black area in Figure 4). The standard size of a pen in the Netherlands is about 10 m^2 (Dierenbescherming, 2015) and, therefore, the standard settings of the model were representing 5 x 2 meters. The walls were represented by brown areas. These walls prevented the pigs to lie outside the pen to be able to measure the correct floor occupation. The areas near the wall (green and blue) the preferred lying places. Ambient temperature could be varied.

Agents in this model were fattening pigs of 62 kilograms and did not grow during a run. This bodyweight was chosen to correspond to pigs in the study of Huynh et al. (2005). Since Huynh et al. (2005) used pigs with a body weight that did not vary, results of this study were used to develop the model. The number of pigs in the pen could be set from 1 to 20 and was by default set as 10, which is an average group size used by farmers in the Netherlands (Dierenbescherming, 2015).

One time step in the model represented 5 minutes. The model ran for one day maximally, which started at 0.00 hours and lasted until 23.59 hours, and, therefore, 1440 minutes.

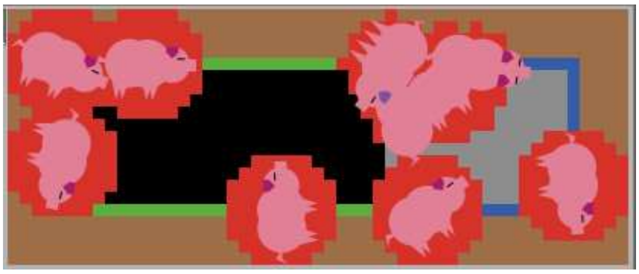


Figure 4. The pigs in the environment. The border of the model represented the wall, with the preferred lying place against it. The grey area represents the slatted floor, the black area represents the solid floor. The circles around the pigs represent the floor occupation of the pigs.

The factors that served as input of the model could be varied to run the model for different situations. While running, the model generated several outputs. Table 2 gives an overview of the input and output of the model.

Table 2. Input and output of the model. The input consists of the parameters that could be varied in the model to generate several outputs while running.

Input	**Output**
Ambient temperature (˚C)	Solid floor occupation (% / time step)
Pen size, width and length (meters)	Slatted floor occupation (% / time step)
Amount of activity peaks (1 or 2)	Total floor occupation (% / time step)
Number of pigs	Average solid floor occupation (% / day)
	Average slatted floor occupation (% / day)
	Average total floor occupation (% / day)
	Amount of pigs reported cannot-lie-preferred (pigs / time step)
	Amount of pigs reported cannot-lie-against-wall (pigs / time step)
	Total times cannot-lie-preferred measured (amount / day)
	Total times cannot-lie-against-wall measured (amount/day)

4.2 Behaviour

Pigs in the model decided each time step whether they wanted to lie down or be active. Figure 5 shows a flowchart of the decision process for the behaviour per pig per time step. The complete code of the model can be found in Appendix I.

When the model started, all pigs were lying. At the start of a time step, it was checked for each pig whether it was lying in the previous step. When the pig was lying in the previous step, it checked if it was willing to stand up. No literature was found on the time pigs stay in their lying position without standing up. Therefore, it was assumed that the maximum time pigs could lie down was related to the times pigs have to stand up to eat/drink or urinate/defecate, which is about once every 41 minutes (Nielsen et al., 1996; Aarnink et al., 1996).

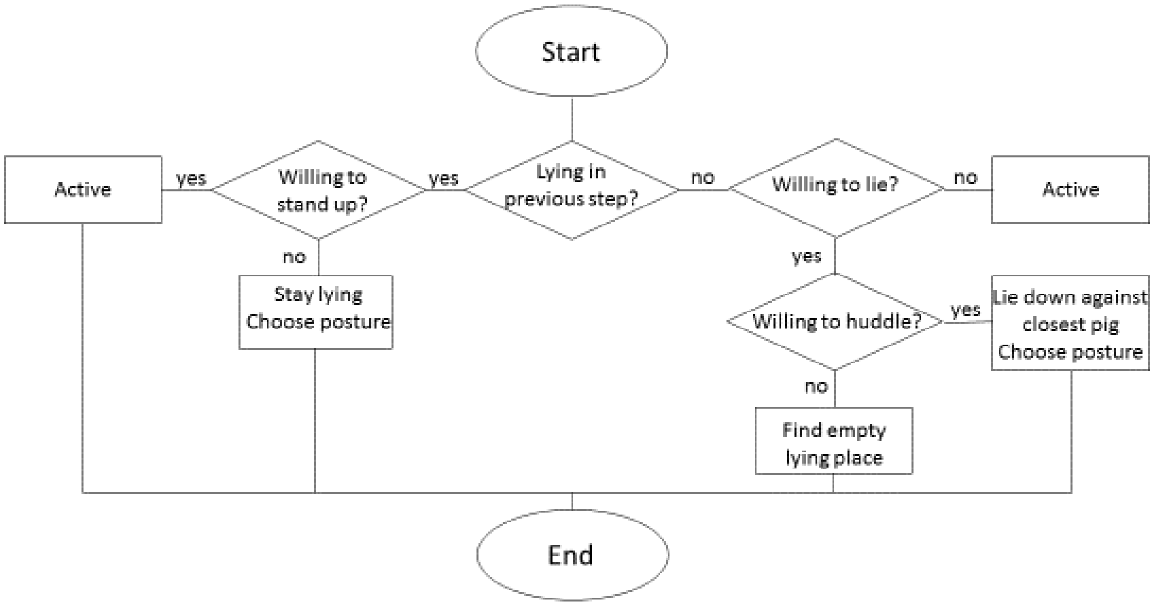


Figure 5. Flowchart with the decision process for each pig per time step. Each time step, all pigs decide their behaviour, according to the flow chart.

When a pig was not lying down, it decided whether it was willing to lie down or be active. This decision was based on a chance. The chance for the choice to be active or to lie down was different per time step and depending on the simulated amount of activity peaks. The chance was based on activity pattern Gonyou et al. (1992) found for pigs with one activity peak or the distribution Ekkel et al. (2003) found for pigs with two activity peaks. Figure 6 shows the chance for pigs to lie down per hour for the activity pattern with one and two activity peaks (chance graph). The average chance for lying down during the day was equal for both distributions (83.29 % for one activity peak and 83.33 % for two activity peaks). Temperature affected this chance. The chance for lying was calculated with: chance for lying (%) = chance graph + ((temperature – 18) * 0.2), based on the results of the study of Huynh et al. (2005). When a pig decided to be active, it randomly moved through the pen.

After a pig decided that it wanted to lie down, it checked whether it was willing to huddle. Whether pigs would huddle or not, was set by a chance. The chance for huddling depended on the ambient temperature and is calculated with the formula chance huddling = 36.3 – ((24 – *temperature*) * 0.048), based on the results of Huynh et al. (2005). When a pig wanted to huddle, it searched for the closest pig and lied down against this pig. Pigs that did not want to huddle, found an empty lying space, of which the procedure is shown in figure 7. Pigs had a preference for a lying area (solid or slatted floor area), depending on ambient temperature. Pigs preferred the solid floor area with ambient temperatures below 19 degrees. When ambient temperatures were 19 degrees or higher, preference shifted towards the slatted floor area (Huynh et al., 2005). Within the preference for the solid or slatted floor area, they preferred to lie against the wall. This was their preferred lying area. When there was no place in the preferred lying area, pigs lied down against the wall in the other area, since they prefer to lie against the wall (Blackshaw, 1980) and reported a 'cannot-lie-preferred'. When there is no place against the wall available at all, pigs would lie in another empty area and reported a 'cannot-lie-against-wall' for all lying places against the wall.

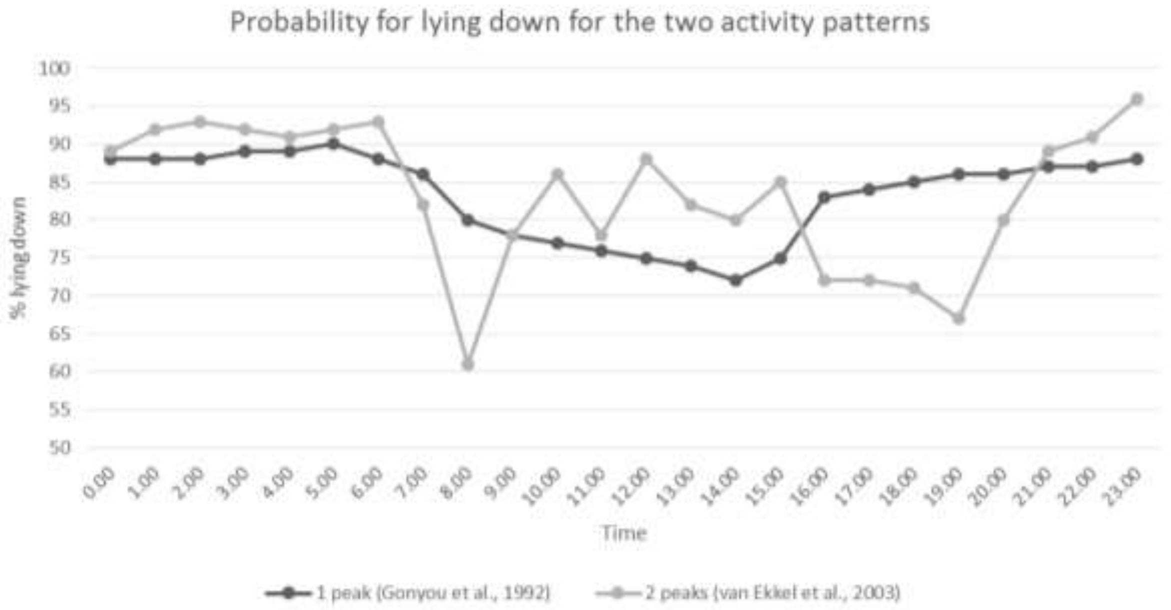


Figure 6. The chance for lying down for the two different activity patterns per hour.

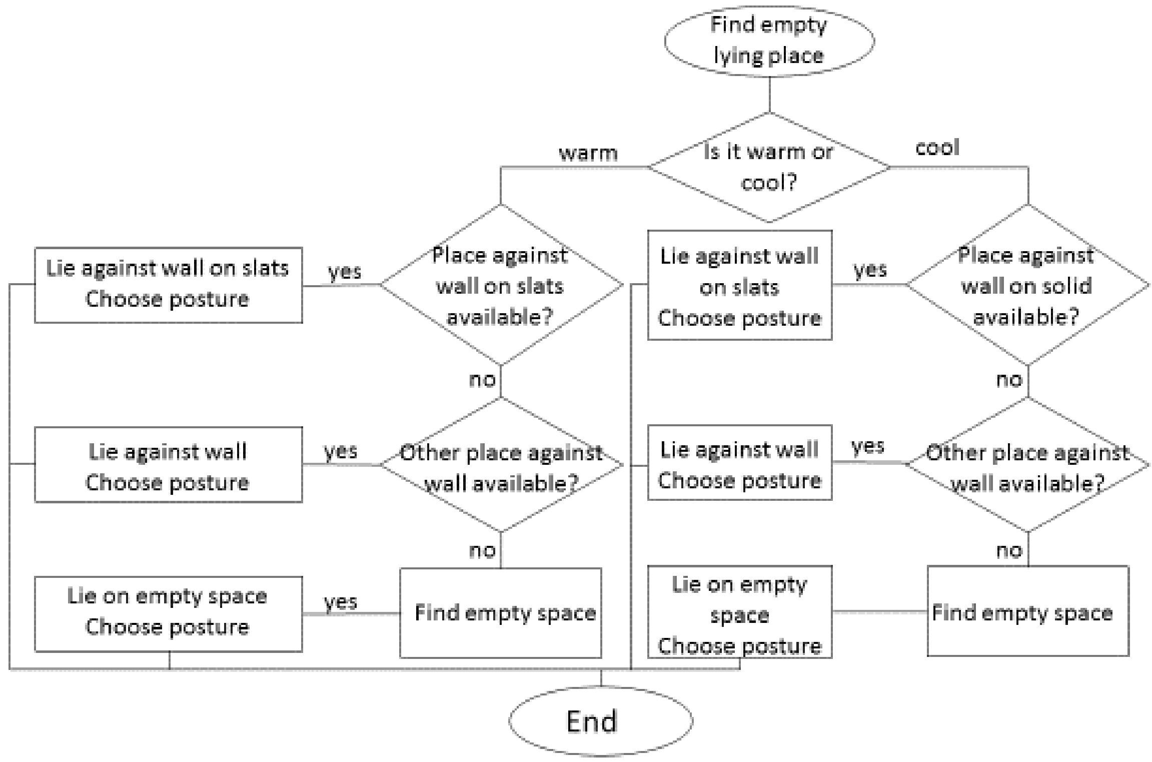


Figure 7. Flowchart for finding an empty lying space

When a pig decided to lie down or was lying down, each time step, it chose a lying posture. The choice for the lying posture was set by a chance, which depended on the ambient temperature. The chance for pigs to lie in lateral posture was calculated by the formula chance lying lateral = 71.66 – ((24 – *temperature*) * 0.008), based on the results of Huynh et al. (2005). The chance to lie in sternal posture was calculated by the formula chance lying sternal = 100 - (12.5 + (24 – *temperature*) * 0.004), based on the results of Huynh et al. (2005). If pigs did not lie lateral, or sternal, they would lie in half-lateral posture.

Only the static space was included in the model, active and social space were not measured. The static space occupation of a pig was assumed to be shaped as a circle and was coloured red. The shape of a circle was chosen, since Netlogo does not recognise the shape of the pig. The radius (R) of this circle was calculated with the formula surface = $R^2 * \pi$, in which the surface was the space occupation of the pigs in different lying postures. The R for a pig in lateral position was 0.48 m. A pig in sternal position had an R of 0.31 and the R for a pig in half-lateral position was 0.40 m. The space occupation for an active pig was assumed to be equal to the space occupation for a pig in sternal lying posture. At the end of each time step, the surface that was occupied by the pigs, the red areas, were added up. At the start of each new time step, all red areas were deleted.

5. Results

5.1 Sensitivity analysis

A sensitivity analysis was conducted to determine the impact of the different variables in the model on the outcomes. The values for the radius for all different postures, the chance for huddling, the variation in chance for resting which depends on temperature and the maximum lying time without standing up were analysed in the standard settings, as used in the model and with an increase and decrease of 50 percent. The effect of varying these variables (one at a time) was tested for floor occupation and cannot-lie-preferred (Table 3). The results show that the radius of the different postures, which is related to the space occupation, had a large influence on total floor occupation. This radius had a smaller influence on the amount of cannot-lie-preferred. The amount of huddling had a moderate influence on the total floor occupation and on the amount of cannot-lie-preferred. The maximum time spent lying without standing up also had moderate influence on the total floor occupation and on the amount of cannot-lie-preferred. The variation in chance for resting which depends on temperature, seemed to have a small impact on both outcomes.

Table 3. Results sensitivity analysis. The parameter values in the model were individually decreased and increased by 50%, while all other factors remained constant.

		Settings			Floor occupation (%)			Cannot-lie-preferred (times/day)		
		+0%	-50%	+50%	+0%	-50%	+50%	+0%	-50%	+50%
Posture radius (m^2)	Lateral	0.48	0.24	0.72	47.4 (100%)	27.1 (57%)	73.4 (155%)	119.7 (100%)	110.0 (92%)	138.4 (116%)
	Half-lateral	0.40	0.20	0.60						
	Sternal	0.31	0.15	0.47						
Huddling (%)		36.3	18.2	54.5	47.4 (100%)	56.7 (120%)	44.8 (95%)	119.7 (100%)	157.4 (132%)	81.1 (68%)
Lying (%)	Variation per ˚C	0.2	0.1	0.3	47.4 (100%)	46.9 (98%)	48.4 (102%)	119.7 (100%)	122.2 (102%)	112.4 (94%)
Max. lying time (min)		41	21	61.5	47.4 (100%)	42.2 (89%)	53.2 (112%)	119.7 (100%)	148.4 (124%)	101.7 (85%)

5.2 Effect of temperature and activity pattern on floor occupation and available lying places

It was chosen to test the effect of temperatures at the boundaries of the thermoneutral zone and the temperatures around the inflection point of the preference for floor type (table 4). The model ran 1000 times for each setting and all runs lasted one day. Table 4 shows that the total floor occupation increases as temperature increases. The difference in floor occupation between the lying pattern with one activity peak and the pattern with two activity peaks is negligible. A larger difference is shown for the total times pigs that could not lie in the preferred lying place per day. The amount of pigs that could not lie against the wall at all was small. Increasing temperature also influences the amount of pigs that could not lie in the preferred area. For temperatures above the warm zone, however, temperature had no effect anymore. This can probably be explained by the decreasing amount of huddling and the influence of total floor occupation, which did only changed for a small amount at higher temperatures.

Table 4. Average outcomes with standard deviations for the different settings after 1000 runs for a group of pigs.

Amount of activity peaks	Temperature (˚C)	Slatted floor occupation (%)	Solid floor occupation (%)	Total floor occupation (%)	Cannot-lie-preferred (times/day)	Cannot-lie-against-wall (times/day)
1	10	18.5 (2.9)	62.1 (0.9)	41.3 (1.2)	35.1 (2.6)	0.000 (0.0)
	18	36.7 (1.6)	52.3 (1.2)	44.5 (1.3)	58.3 (3.8)	0.000 (0.0)
	19	59.8 (1.5)	31.2 (1.3)	45.5 (1.8)	121.0 (3.5)	0.000 (0.0)
	20	62.3 (0.9)	30.1 (1.4)	46.2 (2.7)	127.1 (3.5)	0.012 (0.0)
	30	64.9 (1.6)	30.6 (1.2)	47.8 (1.9)	127.0 (3.2)	0.030 (0.0)
2	10	18.4 (2.9)	62.3 (1.9)	41.4 (1.7)	34.4 (2.6)	0.000 (0.0)
	18	36.6 (1.9)	51.6 (1.1)	44.1 (1.5)	72.6 (3.2)	0.000 (0.0)
	19	59.4 (1.5)	31.9 (1.6)	45.7 (1.4)	113.7 (3.6)	0.000 (0.0)
	20	62.5 (1.0)	30.3 (1.5)	46.4 (0.7)	119.7 (3.1)	0.004 (0.0)
	30	65.1 (1.0)	30.9 (1.8)	48.0 (0.8)	119.6 (3.1)	0.005 (0.0)

5.3 Patterns over the day

Figure 8 illustrates the development of the total floor occupation during the day, for both activity patterns in a thermoneutral environment of 20 degrees Celsius. Patterns for other temperatures are comparable and, therefore, it is chosen to only show the pattern for 20 degrees Celsius. The graph shows that the floor occupation of the total floor is lower during peak times than during non-peak times. The difference in space occupation between peak times and non-peak times can be explained by the static space occupations of the different postures. When pigs are standing, they use less static space than pigs lying down in lateral or half lateral posture. During peak times, more pigs are standing than during non-peak times. During non-peak times, however, the development of the floor occupation for both patterns sometimes differ from each other, for example at 6.00 hour. Although it is not an activity peak time, there is a significant difference in lying chance between the two patterns at these times. This explains the differences that occur outside the peak times.

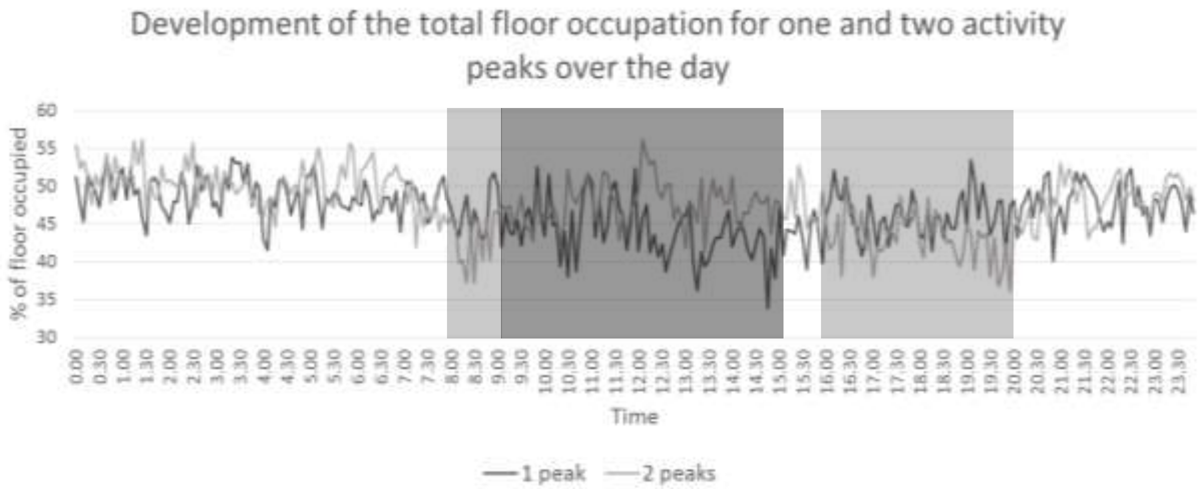
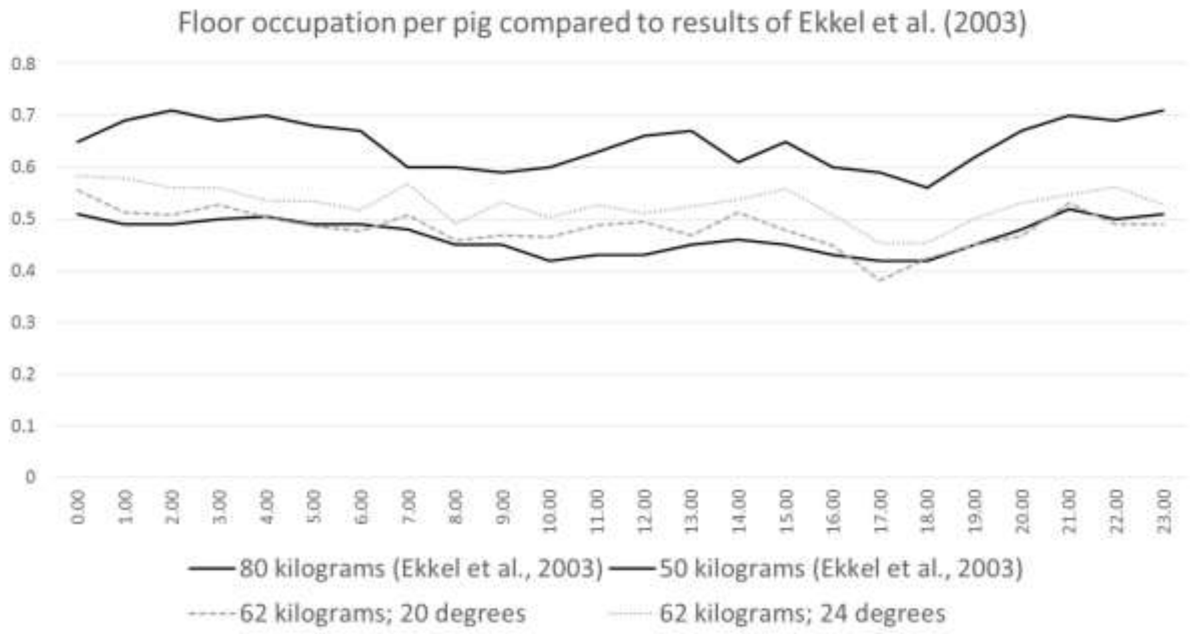


Figure 8. The total floor occupation for activity patterns with one and two activity peaks in a thermoneutral environment of 20 degrees Celsius after 30 runs. The dark box represents the peak time for the pattern with one peak, the light boxes represent the peak times for pattern with two peaks.



A

Figure 9. The development of the floor occupation per pig during the day in the model after 30 runs (solid lines) compared with the outcomes of Ekkel et al. (2003) (dotted lines).

comparison was made between the results on floor occupation in the current study and those found by Ekkel et al. (2003) found on floor occupation (figure 9) to check the validity of the model. The results of pigs with two activity peaks and an ambient temperature of 20˚C and 24 ˚C were used in the graph, since the study of Ekkel et al. (2003) also used pigs with two activity peaks and ambient temperature varied between 20 ˚C and 24 ˚C. Figure 8 shows that the average space occupation per pig for 20 ˚C was slightly higher for pigs of 62 kilograms, used in current study, than for pigs of 50 kilograms, used in the study of Ekkel et al. (2003). Space occupation per pig with an ambient temperature of 24 ˚C was above the space occupation for pigs with an ambient temperature of 20 ˚C and the results of Ekkel et al. (2003) for pigs of 50 kilograms. These results indicate that results of current study on space use are comparable with the results of Ekkel et al. (2003).

Figure 10 shows the amount of pigs that cannot lie in the preferred lying area over the whole day. A difference is shown in total amount of cannot-lie-preferred per day, between the two different activity patterns (table 4). Figure 10, however, gives no decisive explanation for the difference. The difference probably can be explained by the fluctuation in activity between the two patterns. The pattern with one peak only has a moderate fluctuation during the peak time. This pattern is more constant than the pattern with two activity peaks. The pattern with two activity peaks fluctuates more and, therefore, more pigs are willing to lie at the same time.

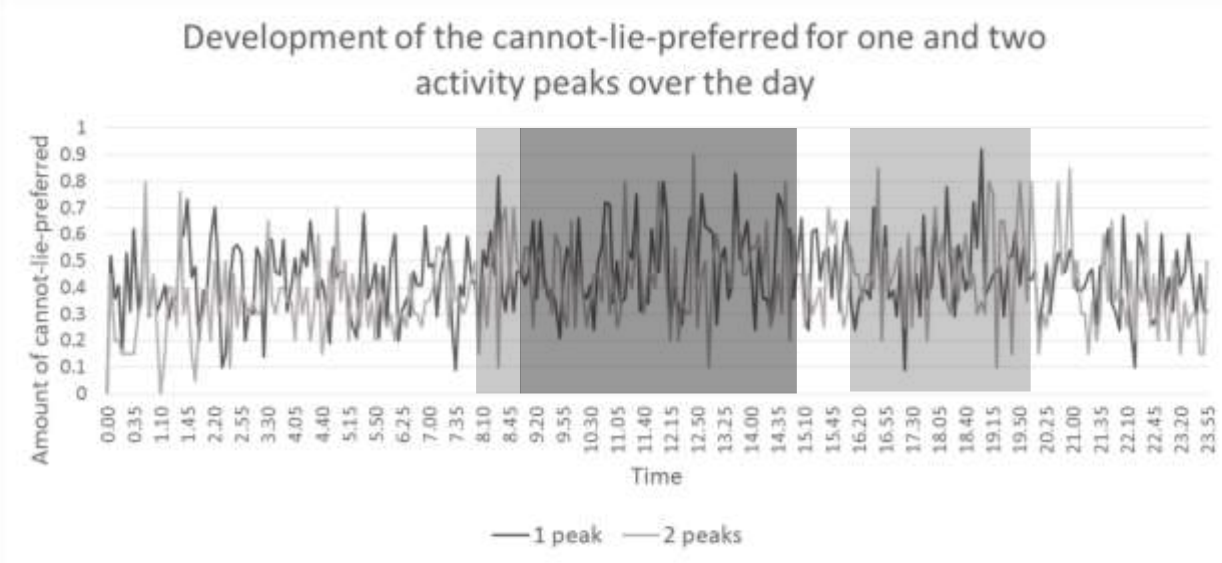


Figure 10. The average distribution of the amount of pigs that cannot lie in the preferred lying place over the day for the different lying patterns at 20 ˚C after 30 runs. The two light boxes represent the activity peak times for lying patterns with two peaks, the dark box represent the activity peak time for the lying pattern with one peak.

6. Discussion

6.1 Explanation of the results

The present study shows that increasing ambient temperature increases overall floor occupation. The increase in floor occupation was expected, since the model was programmed such, that increasing temperature increased lying time and the amount of lying in lateral posture and decreased the amount of huddling. These behaviours increased floor occupation, since a lying pig in lateral or half lateral lying posture has a larger floor occupation than a standing pig. Spoolder et al. (2012) and Hillmann et al. (2004), also found an increase in floor occupation with an increase in ambient temperature. In addition, the pattern found in the current study of floor occupation during the day for pigs with two activity peaks, is in line with the pattern found by Ekkel et al. (2003).

Model results showed no large difference in average floor occupation between the activity patterns with one and two activity peaks. Pigs with a activity pattern with one activity peak, however, have more often difficulties with finding a lying place in the preferred area, near the wall and the preferred floor type, than pigs with two activity peaks. This can be explained by the pattern of activity. The pattern with one peak is more gradually divided over the whole day. The pattern with two activity peaks, has peaks with a high chance for being active and a low chance during non-peak times. Spoolder et al. (2012) found that pigs did not always lie in the lying place that is assumed to be preferred (solid or slatted floor), but did not compare different activity patterns. No explanation was found by Spoolder et al. (2012) for pigs lying in the area that was not preferred, while places were available. Current study shows that a lack of space may play a role in this behaviour, since pigs that do not want to huddle, look for a lying place in which they do not have physical contact with other pigs. Sometimes this leads to lying in a lying place that is not preferred, but is available. When pigs have to lie in a lying place they do not prefer, this can have an influence in maintaining thermo comfort, since the lying place may have an influence on heat loss.

The results indicate that the activity pattern with two activity peaks can be more beneficial for pigs, since the pigs in the model had less problems with finding a preferred lying place. It can, therefore, be advantageous to influence the activity pattern of the pigs. Activity patterns can, for example, be influenced by illumination (Van Putten & Elshof, 1983) or feeding rhythm (Boulos & Terman, 1979).

6.2 Choices made while modelling

While modelling, several choices had to be made to develop the model. The model, thereby, had to be kept as simple as possible and, therefore, boundaries had to be set.

The behaviours included in the model were based on the behaviours of pigs in observational studies and included the averages of group behaviours. The time budget of pigs in the model was based on observed time budgets in empirical studies and included in the model as an equal probability for showing the aspects of lying behaviour for each pigs. Individual variation is, therefore, not included in the model and on average group level, the model should, therefore, give correct results. Individual pigs might have preferences that deviate from average group level. Perceived temperature may, for example, differ among pigs in the same conditions and have an influence on lying behaviour. When pigs respond to each other and their internal needs, instead of responding to external factors, different behavioural patterns might emerge that influence space use and the availability of preferred lying places.

Pigs in the model preferred to lie against the wall. When they could not lie against the wall on the preferred floor type, they would prefer lying against the wall on the other floor type, rather than lying on an open place on the preferred floor area. This assumption is based on the results of

Blackshaw (1980), who found that pigs always preferred lying against the wall. The conclusion was drawn for temperatures between 10 and 20 degrees Celsius. This conclusion is supported by Spoolder et al. (2012), who also found that pigs mostly lie against the wall. For high ambient temperatures, however, pigs might shift their preferences. When the ambient temperature is high, pigs may prefer an open place on the slatted floor, rather than against the wall on the solid floor. Since current study only focusses on temperature within the thermoneutral zone, it was assumed that pigs always preferred to lie against the wall.

To measure the space occupation of a pig in the model, it was chosen to represent the pig as a circle in the model. In reality, however, pigs are more oblong shaped. The occupation of the preferred lying places, might be influenced by the shape. The procedure of finding an empty lying place is based on the circle around the pig. This shape, however, does influence the amount of available lying places. Pigs are more oblong shaped and when they lie with their back against the wall, less lying places are available against the wall, compared to the circle shapes. When making the shape of the pigs oval, the amount of pigs that cannot lie in the preferred lying place might, therefore, increase. When less lying places are available in the preferred area, it might be that pigs will more often choose a posture that fits in between two other pigs to be able to lie against the wall. This might cause the total floor occupation to decrease slightly.

Ambient temperature was included in the model as a non-fluctuating temperature during a run of the model. In reality, however, ambient temperature may fluctuate during the day, due to external influences as outside temperature and heat production of the pigs in the pen (Sällvik & Walberg, 1984). Furthermore, humidity and air velocity also may have an effect on perceived temperature (Boon, 1982b; Verstegen et al., 1987) and can affect lying behaviour (Geers et al., 1986). Pigs might prefer a lying place with a high air speed to cool down, or avoid it to conserve heath (Geers et al., 1986). In conventional pig housing systems, however, the impact of air velocity and humidity is minimal (Song et al., 2013). These effects, therefore, were not taken into account in the model.

When ambient temperature lies within the hot zone, outside the thermoneutral zone, pigs might wallow in their own excretions to increase heat loss and cool down (Kanis et al., 2004). Current study, however, does only focus on temperatures within the thermoneutral zone. Wallowing behaviour to cool down is, therefore, not included in the model. When expanding the model to test the effect of temperatures outside the thermoneutral zone, the possibility for wallowing should be included. It might, however, be that the pigs wallow unintentionally. Pigs separate their lying and excretion location (Aarnink, 1997). A shift in temperature, might, therefore, be related to a change in lying and excretion locations and, therefore, pigs might lie in dirty areas. When pigs wallow, they cool down and their perceived temperature decreases (Van Putten, 1978). Wallowing, therefore, probably will decrease total floor occupation and makes it easier to find a place in the preferred lying area.

In the developed model, it was assumed that the maximum time pigs could lie in one lying bout, was 41 minutes. In reality, the time per lying bout may differ. The effect of this factor, however, is only moderate. The sensitivity analysis showed that the results on cannot-lie-preferred increase or decrease about 20 percent and on total floor occupation 11 percent, when decreasing or increasing the maximum lying time per lying bout with 50 percent. The results are, therefore, limited affected by the choice for this value.

6.3 Future research

Current study focussed on a standard rectangular pen design, since this is the most common shape used in pig housing systems. The model offers opportunities to test for other pen shapes. Pens with a deviating pen design, may have different outcomes than a standard rectangular pen. Pens with different shapes, may have more or other shaped walls, which may influence the results. Pens with more wall surface offer more opportunities to lie against the wall.

The current study focussed on static space requirements of pigs. Next to static space, activity and social space also may have an influence on the total space requirements in pigs. An ABM can be used to measure the activity and social space use, since an ABM can include interactions between individual agents. The space that pigs need to avoid or participate in fights or playing, for example, can be measured with an ABM. With the literature that is currently known, however, it might be difficult to gain a proper image about the exact activity and social space use. Observational studies may be needed to determine how social space is used. Activity space, however, might be easier to include in the model. It is possible to observe the path pigs walk in Netlogo. When including activity space in the model, more behaviours have to be included, like eating, urinating/defecating and playing/fighting behaviour, in order to establish the activity space as accurate as possible.

7. Conclusion

It can be concluded that increasing temperature, increases total floor occupation. There is no difference found in average floor occupation between an activity pattern with one peak and with two peaks. The distribution of the floor occupation over the day, however, is different for both activity patterns. Pigs with an activity pattern with one activity peak have more often difficulties with finding a lying place in the area they prefer than pigs with an activity pattern with two peaks. Increasing temperature leads to more difficulties with finding a lying place in the preferred area for ambient temperatures below and within the comfort zone.

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Appendix I. The code in the model

```
globals [
  slatted-patches               ;; set of grey patches, slatted floor
  solid-patches                 ;; set of black patches, solid floor
  walls                         ;; set of brown patches
  occupied-patches              ;; set of red patches, occupied by lying pigs
  total-time                    ;; ticks * minutes per ticks
  total-resting-time            ;; total-time spent resting
  total-activity-time           ;; total-time spent active
  total-lateral-time            ;; total-time spent lying lateral
  total-sternal-time            ;; total-time spent lying sternal
  total-half-lateral-time       ;; total-time spent lying half lateral
  surface-lateral               ;; surface area that is taken by lying laterally
  surface-sternal               ;; surface area that is taken by lying sternally
  surface-half-lateral          ;; surface area that is taken by lying half laterally
  slatted-patches-occupied      ;; red patches in the slatted area
  solid-patches-occupied        ;; red patches in the solid area
  preferred-lying-area          ;; area against the wall, blue patches
  cannot-lie-on-slatted-floor   ;; pigs willing to lie on slatted floor, but floor is occupied
  cannot-lie-on-solid-floor     ;; pigs willing to lie on solid floor, but floor is occupied
  cannot-lie-against-wall-slatted;; wall on slatted floor is preferred, but is occupied
  cannot-lie-against-wall-solid ;; wall on solid floor is preferred, but is occupied
  cannot-lie-against-wall       ;; all walls are occupied
  have-to-huddle                ;; pigs cannot lie without touching the personal space of another pig
  empty-patches
]

breed [pigs pig]

pigs-own [
  activity-time                 ;; time spent active per pig
  resting-level                 ;; the probability pigs will rest in that tick
  behaviour                     ;; the behaviour (active/resting)
  posture                       ;; posture pigs lying in
  resting-time-increase         ;; the increase in resting time, depending on temperature
  probability-huddling          ;; the probability pigs will huddle
  probability-lateral           ;; the probability pigs will lie lateral
  probability-sternal           ;; the probability pigs will lie sternal
  time-spent-lying              ;; the time pigs spent lying
  personal-space                ;; the increase in space while lying, needed for personal space
]

;;;;;;;;;;;;;;;;;;;
;;;;;;setup;;;;;;
;;;;;;;;;;;;;;;;;;;

to setup
  clear-all
  setup-pen-size
  setup-pigs
  setup-slatted-patches
```

```
  setup-solid-patches
  setup-preferred-lying-area
  setup-walls
  reset-ticks
end

to setup-pen-size  ;; create size of the world, depending on sliders
  resize-world 0 (pen-width * 10) 0 (pen-length * 10)
  set-patch-size (40 / pen-length)
end

to setup-pigs ;; create pigs
  set-default-shape turtles "pig lateral"
  create-pigs number-of-pigs
  [
   setxy random-xcor random-ycor
   set size 10
   set time-spent-lying 0
  ]
end

to setup-slatted-patches ;; set half of the world slatted, grey patches
  set slatted-patches patches with [pycor < (pen-length * 10 * 0.4)]
  ask slatted-patches [ set pcolor grey ]
end

to setup-solid-patches ;; set half of the world solid, black patches
  set solid-patches patches with [pycor >= (pen-length * 10 * 0.4)]
  ask solid-patches [ set pcolor black ]
end

to setup-preferred-lying-area ;; create blue and green borders, these are the preferred lying patches
against the walls
  ask slatted-patches with [abs pycor = min-pycor + 4]
   [set pcolor blue]
  ask slatted-patches with [abs pxcor = min-pxcor + 4]
   [set pcolor blue]
  ask slatted-patches with [abs pxcor = max-pxcor - 4]
   [set pcolor blue]
  ask solid-patches with [abs pycor = max-pycor - 4]
   [set pcolor green]
  ask solid-patches with [abs pxcor = min-pxcor + 4]
   [set pcolor green]
  ask solid-patches with [abs pxcor = max-pxcor - 4]
   [set pcolor green]
end

to setup-walls ;; create brown patches, which represent the walls
  ask patches with [abs pxcor = max-pxcor]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor]
   [set pcolor brown]
```

```
  ask patches with [abs pxcor = min-pxcor]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor]
   [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 1]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 1]
   [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 1]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 1]
   [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 2]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 2]
   [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 2]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 2]
   [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 3]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 3]
   [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 3]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 3]
   [set pcolor brown]
end

;;;;;;;;;;;;;;;;
;;;;;;go;;;;;;
;;;;;;;;;;;;;;;

to go
 set-patches-in-original-colour
 check-time-spent-lying
 check-temperature
 decide-behaviour
 count-occupied-patches
 set total-time total-time + minutes-per-tick
 tick
 if (total-time) >= 1440
 [ stop
  ]
end

to set-patches-in-original-colour ;; to remove all red patches
  ask slatted-patches [set pcolor grey]
  ask solid-patches [set pcolor black]
  ask slatted-patches with [abs pycor = min-pycor + 4]
   [set pcolor blue]
```

```
  ask slatted-patches with [abs pxcor = min-pxcor + 4]
   [set pcolor blue]
  ask slatted-patches with [abs pxcor = max-pxcor - 4]
   [set pcolor blue]
  ask solid-patches with [abs pycor = max-pycor - 4]
   [set pcolor green]
  ask solid-patches with [abs pxcor = min-pxcor + 4]
   [set pcolor green]
  ask solid-patches with [abs pxcor = max-pxcor - 4]
   [set pcolor green]
  ask patches with [abs pxcor = max-pxcor]
     [set pcolor brown]
  ask patches with [abs pycor = max-pycor]
     [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor]
     [set pcolor brown]
  ask patches with [abs pycor = min-pycor]
     [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 1]
     [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 1]
     [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 1]
     [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 1]
     [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 2]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 2]
   [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 2]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 2]
   [set pcolor brown]
  ask patches with [abs pxcor = max-pxcor - 3]
   [set pcolor brown]
  ask patches with [abs pycor = max-pycor - 3]
   [set pcolor brown]
  ask patches with [abs pxcor = min-pxcor + 3]
   [set pcolor brown]
  ask patches with [abs pycor = min-pycor + 3]
   [set pcolor brown]
end

to check-time-spent-lying ;; if pigs have lied more than 41 minutes in one space, they will set their timer to 0 to find a new lying place
  ask pigs
  [
  if (time-spent-lying * minutes-per-tick) >= 41
   [set time-spent-lying 0]
  ]
end
```

```
to check-temperature ;; set all probabilities for behaviour that depend on temperature
 ask pigs
 [
  set resting-time-increase (temperature * 0.2)
  set probability-huddling (36.3 - (24 - temperature) * 0.048)
  set probability-lateral (71.66 - (24 - temperature) * 0.008)
  set surface-lateral 4.9
  set probability-sternal (100 - (12.5 + (24 - temperature) * 0.004))
  set surface-sternal 3.1
  set surface-half-lateral 4.1
  if temperature > 18
  [set personal-space ((temperature - 18) * increased-personal-space-with-high-temperatures)]
 ]
end

to decide-behaviour ;; decide behaviour (active or resting), depending on total time
  ask pigs
  [
  if number-of-peaks = 1
  [
  if total-time < 60
   [set resting-level 88]
  if (total-time) >= 60 and (total-time) < 120
   [set resting-level 88]
  if (total-time) >= 120 and (total-time) < 180
   [set resting-level 88]
  if (total-time) >= 180 and (total-time) < 240
   [set resting-level 89]
  if (total-time) >= 240 and (total-time) < 300
   [set resting-level 89]
  if (total-time) >= 300 and (total-time) < 360
   [set resting-level 90]
  if (total-time) >= 360 and (total-time) < 420
   [set resting-level 88]
  if (total-time) >= 420 and (total-time) < 480
   [set resting-level 85]
  if (total-time) >= 480 and (total-time) < 540
   [set resting-level 80]
  if (total-time) >= 540 and (total-time) < 600
   [set resting-level 78]
  if (total-time) >= 600 and (total-time) < 660
   [set resting-level 76]
  if (total-time) >= 660 and (total-time) < 720
   [set resting-level 75]
  if (total-time) >= 720 and (total-time) < 780
   [set resting-level 75]
  if (total-time) >= 780 and (total-time) < 840
   [set resting-level 73]
  if (total-time) >= 840 and (total-time) < 900
   [set resting-level 70]
  if (total-time) >= 900 and (total-time) < 960
```

```
 [set resting-level 75]
if (total-time) >= 960 and (total-time) < 1020
 [set resting-level 82]
if (total-time) >= 1020 and (total-time) < 1080
 [set resting-level 83]
if (total-time) >= 1080 and (total-time) < 1140
 [set resting-level 84]
if (total-time) >= 1140 and (total-time) < 1200
 [set resting-level 84]
if (total-time) >= 1200 and (total-time) < 1260
 [set resting-level 85]
if (total-time) >= 1260 and (total-time) < 1320
 [set resting-level 85]
if (total-time) >= 1320 and (total-time) < 1380
 [set resting-level 86]
if (total-time) >= 1380 and (total-time) < 1440
 [set resting-level 86]
]
 if number-of-peaks = 2
[
if total-time < 60
 [set resting-level 89]
if (total-time) >= 60 and (total-time) < 120
 [set resting-level 92]
if (total-time) >= 120 and (total-time) < 180
 [set resting-level 93]
if (total-time) >= 180 and (total-time) < 240
 [set resting-level 92]
if (total-time) >= 240 and (total-time) < 300
 [set resting-level 91]
if (total-time) >= 300 and (total-time) < 360
 [set resting-level 93]
if (total-time) >= 360 and (total-time) < 420
 [set resting-level 93]
if (total-time) >= 420 and (total-time) < 480
 [set resting-level 82]
if (total-time) >= 480 and (total-time) < 540
 [set resting-level 61]
if (total-time) >= 540 and (total-time) < 600
 [set resting-level 78]
if (total-time) >= 600 and (total-time) < 660
 [set resting-level 87]
if (total-time) >= 660 and (total-time) < 720
 [set resting-level 78]
if (total-time) >= 720 and (total-time) < 780
 [set resting-level 88]
if (total-time) >= 780 and (total-time) < 840
 [set resting-level 82]
if (total-time) >= 840 and (total-time) < 900
 [set resting-level 80]
if (total-time) >= 900 and (total-time) < 960
 [set resting-level 86]
```

```
   if (total-time) >= 960 and (total-time) < 1020
    [set resting-level 72]
   if (total-time) >= 1020 and (total-time) < 1080
    [set resting-level 72]
   if (total-time) >= 1080 and (total-time) < 1140
    [set resting-level 71]
   if (total-time) >= 1140 and (total-time) < 1200
    [set resting-level 67]
   if (total-time) >= 1200 and (total-time) < 1260
    [set resting-level 80]
   if (total-time) >= 1260 and (total-time) < 1320
    [set resting-level 89]
   if (total-time) >= 1320 and (total-time) < 1380
    [set resting-level 91]
   if (total-time) >= 1380 and (total-time) < 1440
    [set resting-level 96]
   ]

 let x random-float 100
 ifelse x <= ( resting-level + resting-time-increase)
   [rest]
   [move]
  ]
end

to move ;; the move procedure
   set shape "pig"
   move-to one-of patches with [pcolor = grey or pcolor = black]
   set heading random 360
      ask patches in-radius (surface-sternal)
  [set pcolor red]
   set time-spent-lying 0
   set activity-time activity-time + minutes-per-tick
   set total-activity-time total-activity-time + minutes-per-tick
   set behaviour "active"
   set posture "none"

end

to rest ;; rest procedure, if pigs lied in previous tick and have not lied for 41 minutes, they will not find a new lying place en only check posture. Otherwise, they find a new lyingplace
    set total-resting-time total-resting-time + minutes-per-tick
    set behaviour "resting"
    if time-spent-lying = 0
        [check-solid-slatted
         check-huddling]
    check-posture
end

to check-solid-slatted ;; depending on temperature, move to solid/slatted floor. If these are not available, pigs move towards a random red patch
    ifelse temperature > 18
```

```
   [
    ifelse any? patches with [pcolor = grey]
    [move-to one-of patches with [pcolor = grey]]
    [ifelse any? patches with [pcolor = black]
      [move-to one-of patches with [pcolor = black]]
      [move-to one-of patches with [pcolor = red]]
     ]
   ]
   [
    ifelse any? patches with [pcolor = black]
    [move-to one-of patches with [pcolor = black]]
    [ifelse any? patches with [pcolor = gray]
      [move-to one-of patches with [pcolor = gray]]
      [move-to one-of patches with [pcolor = red]]
     ]
   ]
end

to check-huddling ;; depending on probability huddling, decide whether to huddle or not
  ifelse temperature > 32
  [not-huddle]
  [ifelse temperature < 10
    [huddle]
    [if any? patches with [pcolor = red]
     [
      let x random-float 100
      ifelse x <= probability-huddling
       [huddle]
       [not-huddle]
     ]
    ]
   ]
end

to huddle ;; find closest pig and huddle against it
  let closest-pig min-one-of other turtles [distance myself]
  move-to closest-pig
  fd -3
  if pcolor = brown
    [
     rt random 360
     fd 1
     huddle
    ]
end

to not-huddle ;; find an available empty space (preferences depend on temperature) with no pigs in-radius 5
  set empty-patches patches with [not any? pigs in-radius 6]
  ifelse temperature < 18
  [
   ifelse any? empty-patches with [pcolor = green]
```

```
    [move-to one-of empty-patches with [pcolor = green]]
    [ifelse any? empty-patches with [pcolor = blue]
      [move-to one-of empty-patches with [pcolor = blue]
       set cannot-lie-against-wall-solid cannot-lie-against-wall-solid + 1]
      [ifelse any? empty-patches with [pcolor = black]
        [move-to one-of empty-patches with [pcolor = black]
         set cannot-lie-against-wall cannot-lie-against-wall + 1]
        [ifelse any? empty-patches with [pcolor = gray]
          [move-to one-of empty-patches with [pcolor =  gray]
           set cannot-lie-on-solid-floor cannot-lie-on-solid-floor + 1]
          [move-to one-of empty-patches with [pcolor = red]
           set have-to-huddle have-to-huddle + 1]
        ]
      ]
    ]
  ]
  [
   ifelse any? empty-patches with [pcolor = blue]
    [move-to one-of empty-patches with [pcolor = blue]]
    [ifelse any? empty-patches with [pcolor = green]
      [move-to one-of empty-patches with [pcolor = green]
       set cannot-lie-against-wall-slatted cannot-lie-against-wall-slatted + 1]
      [ifelse any? empty-patches with [pcolor = gray]
        [move-to one-of empty-patches with [pcolor = gray]
         set cannot-lie-against-wall cannot-lie-against-wall + 1]
        [ifelse any? empty-patches with [pcolor = black]
          [move-to one-of empty-patches with [pcolor =  black]
           set cannot-lie-on-slatted-floor cannot-lie-on-slatted-floor + 1]
          [move-to one-of empty-patches with [pcolor = red]
           set have-to-huddle have-to-huddle + 1]
        ]
      ]
    ]
  ]
end


to check-posture ;; depending on temperature and probability, choose posture
  set time-spent-lying time-spent-lying + 1
  let x random-float 100
  ifelse x <= probability-lateral
    [lie-lateral]
    [ifelse x >= probability-sternal
       [lie-sternal]
        [lie-half-lateral]
    ]
end

to lie-lateral
  set shape "pig lateral"
  set posture "lying lateral"
  set total-lateral-time total-lateral-time + minutes-per-tick
```

```
  ask patches in-radius (surface-lateral + personal-space)
  [set pcolor red]
end

to lie-sternal
  set shape "pig sternal"
  set posture "lying sternal"
  set total-sternal-time total-sternal-time + minutes-per-tick
  ask patches in-radius (surface-sternal + personal-space)
  [set pcolor red]
end

to lie-half-lateral
  set shape "pig half lateral"
  set posture "lying half-lateral"
  set total-half-lateral-time total-half-lateral-time + minutes-per-tick
  ask patches in-radius (surface-half-lateral + personal-space)
  [set pcolor red]
end

to count-occupied-patches ;; cound the red patches
  ask slatted-patches with [pcolor = red]
    [set slatted-patches-occupied slatted-patches-occupied + 1]
  ask solid-patches with [pcolor = red]
    [set solid-patches-occupied solid-patches-occupied + 1]
end
```