Maejo Int. J. Sci. Technol. **2022**, *16*(01), 25-39

Maejo International Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Technical Note

Passive cooling strategies for cattle housing on small farms: A case study

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Received: 29 October 2021 / Accepted: 22 February 2022 / Published: 24 February 2022

Abstract: Small-scale beef cattle farmers in tropical zones face climate variability, especially during the hot summer months. As the temperature rises, beef cattle are exposed to heat stress, resulting in lower beef quality and production yields and higher costs of livestock farming. With many restrictions on the part of smallholders raising beef cattle, one way to reduce this impact on small farms is to design cattle housing that helps protect against direct and indirect solar heat and removes the heat from the house effectively. This study has used the concept of passive cooling design to improve the beef cattle houses of smallholders. The farmers' existing limitations, both in capital and construction capacity, are taken into account. Housing size, roof shape and roofing materials were modified to give adequate protection against heat and increase cross and stack ventilation. In addition, the positions of the buildings around the cattle house were rearranged to allow more draught into the house. After renovation, the indoor temperature was observed to be up to 5°C lower than the outside temperature, and the humidity was reduced by 60–72%**.**

Keywords: passive cooling, cattle housing, small farms, livestock

INTRODUCTION

Smallholding farmers are the world's largest food suppliers and provide nearly 70% of the world’s food supply [1]. They are likely to become more important in the future as a result of population increase and the demand for food including that from cow products. Smallholding cattle farmers, however, have many problems of animal husbandry, such as shortage of funding, lack of technical knowledge, having no land of their own, and absence of public utility (e.g. electricity grid) owing to the farms being located in rural areas [2-5]. Thus, they use low-cost cattle farming strategies for beef production with traditional beef cattle housing made from inexpensive materials without engineering design and fully open buildings that are directly linked to the climate and natural conditions in the area [6]. For this reason, the climate condition around the beef cattle housing greatly affects that inside the house, which leads to a wide range of quality and quantity of products obtained from beef cattle [7, 8]. Studies of Falk et al. [9], Samer [10] and Hatem et al. [11] indicated that the temperature inside an open cow shed tends to be higher than outside during the hottest hours of the day in tropical areas. Chiang Mai province has the largest number of beef cattle farms in northern Thailand, and 98% of them are small farms. Smallholding farmers in Chiang Mai have many problems and limitations of their cattle farming that are not different from those occurring in other smallholders' farms in developing countries around the world. They are facing extreme weather conditions more frequently, especially during the summer. Since the past 10 years, Chiang Mai has had more than 10 days in which the temperature exceeds 40°C each year, which considerably affects the temperature inside the beef cattle housing. If the environment in the house is hot, the beef cows will feel uncomfortable suffering from heat stress and show typical visible signs such as high respiratory rates, open-mouth breathing, restlessness, decreased activity, and eating and ruminating less [12-14].

Garcia [15] found that cattle eat 7.8% less of the amount of dry food consumed in one day when the temperature rises 1°C, resulting in their becoming easily ill and slower growth rates. In addition to decreasing the productivity of the beef cows, higher temperatures also lead to higher farm operating costs [16], causing some smallholding farmers who are unable to cope with this condition to stop their cattle farming [2]. Moreover, Gasparrini et al. [17] demonstrated that temperatures in Southeast Asia, including Thailand, are likely to become higher in the future. The worst-case scenario of the study showed that the average annual temperature would rise 3.85°C in the next 50 years and that the region's hot season will be two months longer due to global warming. This is likely to affect the number of smallholding beef cattle farmers in Thailand, including the quantity, quality and price of beef products in the future.

There has been a growing interest in farming strategies to cope with higher temperatures, such as the development of heat-tolerant cow breeds, the development of vaccines and supplements, and the development of technology for environmental control for confined livestock housing [5, 18]. However, as they all considerably increase farm operating expenses, and also with the many limitations of smallholding farmers in Thailand mentioned above, most smallholding farmers are unable to afford and accommodate the proposed strategies [2, 3]. Thus, finding one that works under the farmers' constraints can be challenging.

The passive cooling strategy is a basic concept that originates from the design of traditional buildings in tropical regions. This strategy has received much attention recently since it can save up to 50–70% of cooling energy by use of natural conditioning to achieve optimal and healthy living conditions. The forms and elements of building design for encouraging natural ventilation and preventing solar heat gain, thus reducing the temperature inside the building, are a major part of passive cooling strategy [19]. Studies [8, 20] have indicated that it is possible to use passive design strategies to solve indoor climate problems in animal houses and improve animal comfort and welfare. The objective of this study is to apply passive cooling techniques to the cattle house taking into account the constraints of smallholding farmers. A small farm in Chiang Mai was used as a case study. For the house improvement, a focus was given on maintaining the original building as much as possible to save construction costs while effectively reducing the temperature. In addition, the modifications should be carried out by the farm owner. The existing conditions of the house were analysed and the data were used to decide on passive cooling techniques for housing improvement.

PASSIVE DESIGN STRATEGIES FOR HOT-HUMID CLIMATE

Passive design is a traditional design that takes advantage of the natural surroundings and climate to protect buildings from extreme weather and enhances user comfort without using any electrical device. The strategies can help reduce energy consumption and CO_2 emission, which is economical and environmentally friendly [19]. As passive design strategies are specific to climates, the design strategies may change to meet individual requirements and vary with the local climate to achieve a specific microclimate. For example, buildings in cold climate require promoting heat gain and resisting heat loss, so thermal mass is used to increase the temperature by trapping the heat of the sun, while buildings in tropical climate need a reduction of temperature by preventing direct and indirect solar gains into the building. Therefore, the application of passive design for buildings is based on individual cases in which the designers must know the specific climate data, building type and user's comfort requirements, which can be those for humans, animals or plants as input for the design [21, 22].

The climate of Chiang Mai, as in most of Thailand, is tropical, causing the weather in Chiang Mai to be hot and humid almost year-round. Therefore, the passive design focuses on using existing resources to create cooling inside the buildings, prevent heat gain to the buildings and remove excess heat from the buildings. The strategies of passive cooling design can be divided into three main approaches (Figure 1): design for pre-cooled air entering the building (A), building envelope design for preventing and reflecting heat gain (B), and design for increasing natural ventilation inside the building to remove unwanted heat (C).

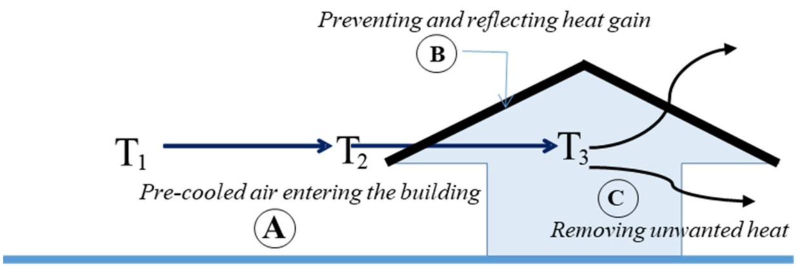

Figure 1. Three main approaches of passive cooling design

There are many passive cooling strategies that could be applied in buildings, such as solar shading design, green roofing, facade design, void design, wind tower, evaporative cooling, earth air tunnel and desiccant cooling. However, only some strategies can be applied in a fully opened cattle house, subject to the topography, functional requirements of the building, and budget [21]. For this study, the farm layout, size of cattle house, roof shape and insulation material were considered.

Chiang Mai is located at latitude 18.79038 and longitude 98.98468 (UTM: 390000E-560000E, 1900000N-2230000N) in northern Thailand. It covers an area of approximately 22,061 km^2, 95% of which are agricultural and forest areas. The climate of Chiang Mai can be divided into three distinct seasons, namely hot, rainy and cool seasons. Summer is between mid-February and May, during which the daytime temperature starts to rise and often reaches 35°C (95°F) with peaks above 40°C (105°F) in April since it is the month that receives the largest amount of solar radiation, especially from 11 am to 4 pm (Figure 2). The monsoon season in Chiang Mai is from May to October, and the mean annual rainfall is approximately 1,000 mm (40 in.), with a peak in August. During mid-November and January, when the north-east monsoon arrives from China, it is the cool season, and the coldest temperature is usually in January. Due to a more severe weather in the past 10 years, the summer in Chiang Mai tends to expand, starting from the end of January to early June, and unusually hot summer days (more than 40°C) have become more common. The hottest temperature ever recorded in Chiang Mai was 43.5°C on April 29th, 2016.

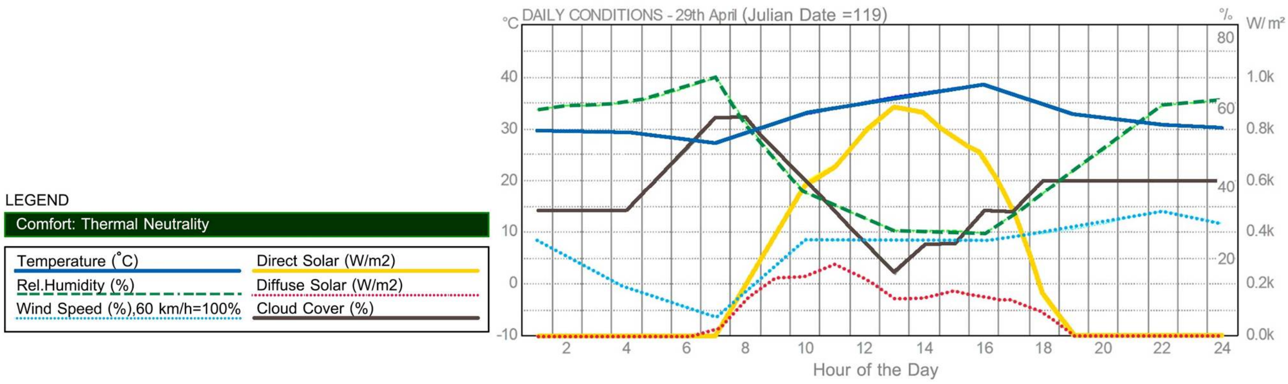

Figure 2. Daily conditions in Chiang Mai from Autodesk Ecotect Analysis [23]

From the data retrieved from Ecotect software [23], the prevailing wind direction and wind speed in Chiang Mai are different each month. The prevailing winds, strong in winter, are north-easterly wind from October to January while westerly and southerly winds are in the other months. In April south-western local wind is the prevailing wind, and the mean daily wind speed is approximately 2.4 m/s.

The majority of studies on heat stress in livestock focus on two main environmental factors: temperature and relative humidity. The effects of temperature and relative humidity can be calculated by using the temperature-humidity index (THI) formula. Normally, THI is used in the assessment of cattle which suffer heat stress with serious consequences on their productivity and on the quality of their final output [13, 24]. THI calculations by Mader and coworkers [25] are widely used in livestock. The THI formula is $THI = (0.8 \times Tdb) + [(RH/100)\times (Tdb - 14.4)] + 46.4$, where Tdb is the dry bulb temperature (°C) measured in the shade and RH is the relative humidity (%), which is divided by 100 to express the percentage in decimals.

The result from the THI calculation indicates when the cows are becoming heat-stressed and to what degree appropriate cooling methods can be used. When THI is 72 or below, most cows are comfortable. They are likely to begin experiencing heat stress when THI exceeds 72. They are seriously affected and their production is significantly lost when THI exceeds 78. The cows will show signs of severe stress and may ultimately die when THI rises above 88.

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ADVANTAGES AND DISADVANTAGES OF EXISTING BEEF CATTLE HOUSING

The beef farm in this case study was located at latitude 18.96603 and longitude 98.97546 in San Sai district, Chiang Mai. The farm consisted of five cottages: the beef cattle house, a cow dung drying shelter, a straw shed, a garage and a farmhouse. The longest side of the beef cattle house was at 66°N, which helped reduce the temperature inside the house since the optimum orientation of a building area in a tropical climate is facing east or north and its major openings can greatly influence the solar heat gain, wind speed and shade for the house [11]. The straw shed was located south of the beef cattle house while the garage and farmhouse were south-east and the cow dung drying shelter was south-west next to the cow housing, as shown in Figure 3. These positions of buildings that were near to one another caused a reduction in wind velocity and a change in wind direction [22]. Especially the location of the cow dung drying shelter directly obstructed the prevailing wind moving through the cow housing during the hot season.

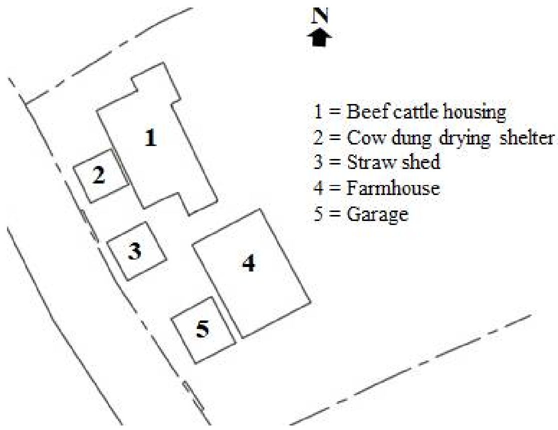

Figure 3. Farm layout

There were 11 cross-bred beef cows in the farm, the body weight of the fully grown cows being 600-650 kg. A loose housing system combined with a free-ranging system was used. The cattle house was a fully open building 8.25 metres wide, 12.5 metres long and only 1.95 metres high without any sidewalls (Figure 4). The cattle housing was relatively low, which reduced indoor natural ventilation and might increase heat gain [11, 26]. The area for 11 beef cows, together with facility area, was slightly less than the standard [27, 28]. The structure of the house was of a traditional one, semi-temporarily built from natural and inexpensive materials available locally, such as bamboo, solid wood and pre-cast concrete columns, with a combination of gable and lean-to roofs without a ceiling. Galvanised zinc sheets were used as roofing material since to the farm owner they were cheaper, durable, lightweight, easy to install and easy to find in the local supply stores near the farm. Although a galvanised zinc roof has many advantages, it is a major contributor to temperature increase in the house due to its high thermal conductivity (114.7 W/mK) [29, 30].

The floor surface of the house was not covered with any finish material, which could reduce the indoor temperature and body temperature of the beef cows when they lay on the ground [31, 32]. If the cow housing has low ventilation and a poor drainage system, the ground may be a source of diseases that negatively affects the cows' health [10]. Moreover, dense nets which retard air flow were installed as a protection against mosquitoes and other biting flies (Figure 5). From the investigation of the barn condition during the day, it was quite hot with no air movement and dim with a musty smell. The house floor was always wet (Figure 6) and there were still many insects even though dense nets were used all day.

Figure 4. Beef cattle house in the case study in San Sai district, Chiang Mai

Figure 5. Installed dense nets

Figure 6. Wet ground floor

The temperature, relative humidity and wind speed inside and outside the cattle house before renovation were measured using digital weather measuring tools for 9 days, i.e. 9–17 June 2019 during 11 am–4 pm, which is the hottest time of the day. Figure 7 shows that the temperature and relative humidity inside the house are between 32–38°C and 60–72%, respectively, which are higher than those outside the house. Consequently, the heat stress levels of the cows using THI were moderate, especially during 3–4 pm, and the highest heat stress level reached 91. During 3–4 pm and even in the evening when the temperature around the house has decreased, the temperature inside the house is still high and 2°C higher than the outside temperature (Figure 7). The temperature inside the house tends to decrease slower than the outside temperature. Moreover, the air movement in the house was very low or without airflow (0–0.1 m/s), even though there were strong winds outside.

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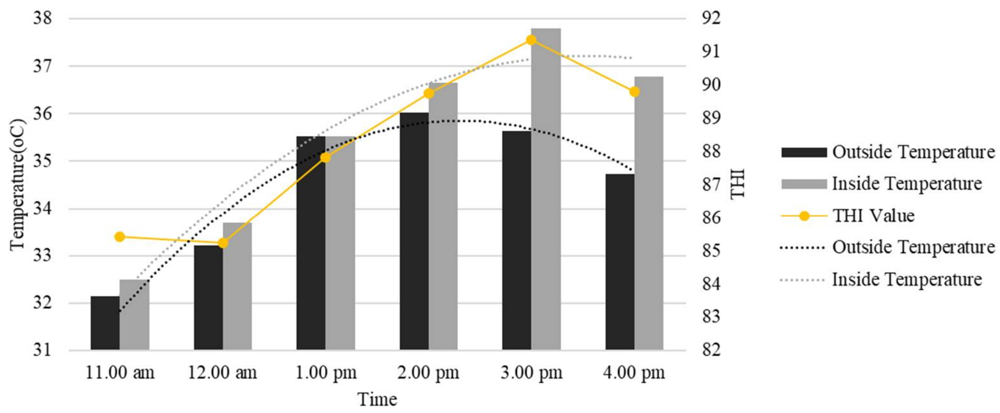
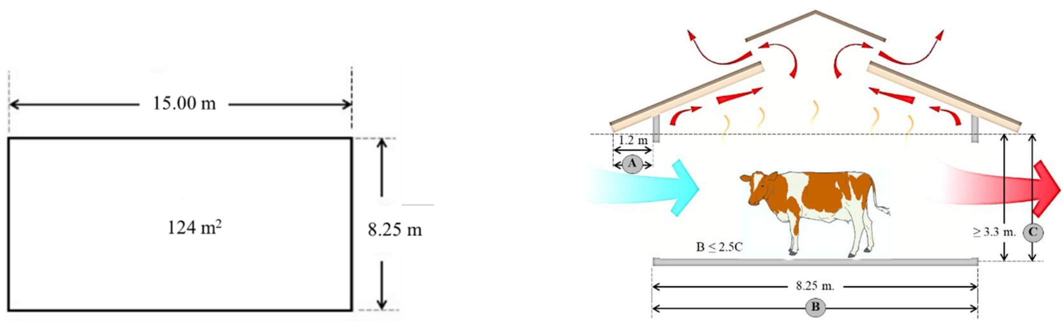


Figure 8. Climate condition outside and inside cattle house before improvement

METHODOLOGY

Using the standard of the Department of Livestock [27], the housing area for 11 beef cows, together with facility area of approximately 40% of the cows' area, such as walkways, food troughs, and drainage troughs [28], was calculated to be 124 m^2. Using the existing width of the beef cattle house (8.25 m) to save renovation costs, it should be approximately 15 m long (Figure 8a). In addition, an optimal height of the cattle house can increase cross ventilation, resulting in air exchange and cooling during the hot weather by removing the heat, moisture and odour and bringing in drier and cooler outside air. If the housing is too wide, it will cause stagnant air inside the house. The distance between the inlet and outlet should be less than 2.5 times the height of the house [33] because it will provide the most efficient ventilation. Moreover, the house should be at least 3 m in height, from the eaves to the floor [11, 34]. Therefore, if the cow house is 8.25 m wide, the height between the eaves and floor should be more than 3.3 m (Figure 8b).



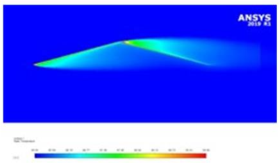
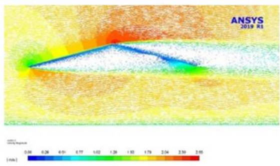
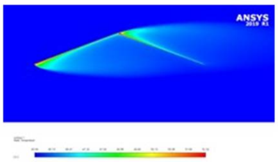
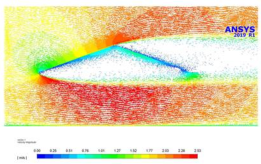
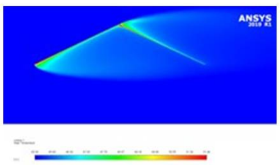
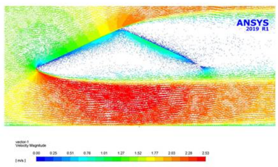
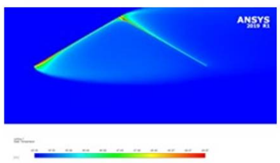
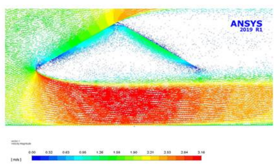
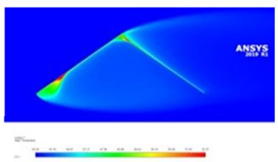
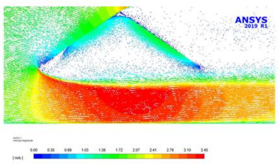
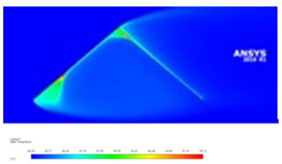
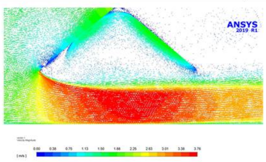
(a) (b)

Figure 9. Cattle housing plan (a) and section (b)

The amount of heat which is trapped in the attic area and the poor design of the structure are the main reasons for the discomfort of animals in open housing [35]. If the roof has a low angle or is flat, the heat will accumulate in a wide area under the roof and go down to the lower area, creating a higher indoor temperature, especially during peak hours in a hot climate region. For passive cooling strategy in roof design, an optimum roof pitch with ridge vents is a suitable strategy that aims to increase stack ventilation and reduce heat transfer from the roof surface to the house [36]. The design of the roof begins with the determination of an appropriate roof slope. Taleb [21] suggests that an optimal roof slope for ventilation can be determined by the proportion of rise and run. The pitched roof should have a rise of more than one-third of the run. Based on this principle and using the formula $\theta = \text{Tan}^{-1}(1/3)$ to find the roof angle, the angle should not be less than 18.5 degrees.

By simulating the heat accumulation and air movement rate of six roof slopes using ANSYS program, it was found that a roof angle of 43.5 degrees has a large area of low temperature (dark blue area) while roof with 18.5- and 23.5-degree angles have a higher air speed (Table 1). Although a high-slope roof can significantly reduce heat accumulation in the attic area, if it is too steep, the air speed in the building will be lower due to the separation of airflow [37, 38]. In addition, considering the cost of building a roof, it was found that every 5-degree rise raises the cost by approximately 7%. Thus, 18.5-degree roof slope seems to be both efficient and economical for ventilation.

Table 1. Simulation of heat accumulation and air speed for different roof slopes and cost increment

Roof angle (Degrees)	Heat accumulation in attic area	Air speed	Incremental cost (%)
15°			±0.00
20°			+2.78
25°			+6.64
30°			+11.59
35°			+18.00
40°			+26.09

In addition, the roof should have a raised ridge and a small gap underneath, or a ridge vent, that creates vertical movement of air from differences in air pressure, temperature and density inside and outside the housing. Longer stacks will typically increase airflow. As illustrated in Figure 9, the width of the opening in the ridge cap (D) and the height of the ridge cap (E) were calculated according to the design principles for ventilation. Liberati et al. [37] suggested that the open ridge should generally be designed to provide 5 cm of opening for every 3 m of roof span, i.e. open ridge (m) = roof span (m)/3 * 0.05. However, the opening should be at least 0.3 m. As the roof span is 10.65 m (Figure 8b), the open ridge size should be 0.18 m, so the minimum ridge opening (D) is 0.3 m. For the ridge cap height, it should be at least half of the open ridge size or 0.15 m.

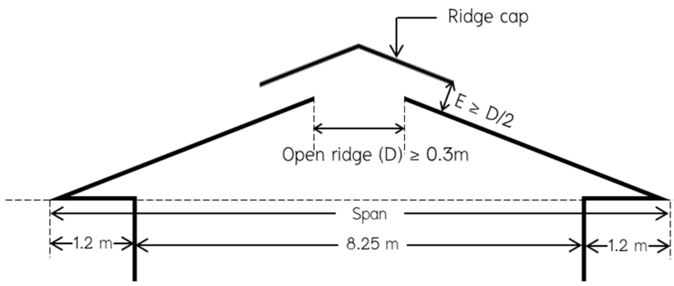


Figure 9. Open ridge and ridge cap

The thermophysical property of roofing material used also strongly affects the heat flow by absorbing and accumulating heat in the form of sensible heat [39]. The preferred roofing materials are those with low density, low thermal conductivity, and high thermal resistance to reduce heat flow through the roof in an uninsulated cattle house. The cool roof performance can be measured by the solar reflex index (SRI), the minimum value of which must be 30% for sloped roofs [40]. Also, different roofing materials have their optimum range of roof slope, and those for small farms must be affordable, durable in hot and humid climate and easily installed [38].

Table 2. Features of roofing materials [30, 35, 40]

No.	Roofing material	Slope (degree)	Cost (Baht/m^2)	Lifetime (year)	Density (kg/m^3)	Thermal conductivity (W/m-K)	SRI (%)
1	Wood shingle	>30	1,500–2,000	< 10	1800	0.08	17
2	Clay tile	>30	600–1,000	> 20	1900	0.84	33
3	Cement tile	>30	380–500	> 20	1700	0.397	25
4	Concrete tile	25–40	700–1500	> 20	2400	0.993	31.7
5	Ceramic tile	25–40	2000–3000	> 20	2100	0.338	59–72
6	Corrugated fibre cement	>15	170–200	> 20	2000	0.395	25
7	Asphalt shingle	>10	1000–2,000	> 10	1500	0.421	22
8	Galvanised iron	>4	150–200	< 10	7800	60	61
9	AluZinc steel	>4	300–400	< 15	6300	114.7	61
10	Polycarbonate	>15	500–700	< 10	1950	0.29	14
11	Fibreglass reinforced plastic	>4	300–400	< 15	150	0.13	7

By comparing 11 conventional roofing materials in Thailand (Table 2), it was found that there are only six (Nos. 6-11) that are suitable for 18.5-degree sloping roof installation. Considering the thermal conductivity and heat capacity as well as the installation cost, it was found that fibre cement is the most suitable roofing material in this renovation. Although it lacks outstanding thermal protection property, it is reasonable in terms of price, durability, availability and ease of installation.

Another important factor to be considered is the housing orientation. In Chiang Mai where the climate is relatively hot and humid with sunlight year-round, an orientation that would reduce the exposure to solar radiation and increase natural ventilation and shading should be adopted [20]. In April when the temperature is highest in Chiang Mai, the dominant wind blows to the south and south-west. The maximum wind speed is 40 km/h south, and the average wind speed is 25 km/h. Therefore, the longest side of the cattle housing should be 192.5°N (or 12.5°N) to take in the south-west local wind as much as possible. However, although the existing cowshed was not exactly 12.5°N, its longest side was 66°N, which was still in an east-west orientation and somewhat suitable for trapping the summer wind and usually led to 85–100% shading during the day with less solar radiation during the summer [11].

RESULTS AND DISCUSSION

The renovation focuses on cost saving by retaining the original structure and materials as much as possible and using waste or cheap materials that can be purchased locally. In addition, the farmers must be able to make improvements on their own to reduce the cost of labour in construction (Figure 10).

Figure 10. Farm owner in San Sai district, Chiang Mai renovating the cattle house

The house was resized from 103 m^2 to 124 m^2 to accommodate 11 head of beef cattle. The width of the house was fixed at 8.25 m, but the length was changed from 12.5 m to 15.0 m, and the height was raised from 1.95 m to 3.3 m. The roof was adjusted to slope at an angle of 18.5 degrees with a raised ridge of 0.15 m and a small gap of 0.3 m underneath. The roofing material was changed from galvanised iron to corrugated fibre cement tile. The inside area of the house was divided into two paddocks with a walkway in the middle, similar to the original pattern, as shown in Figures 11 and 12.

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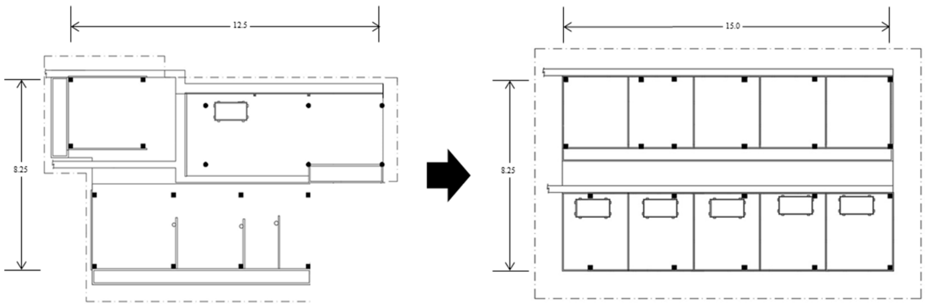
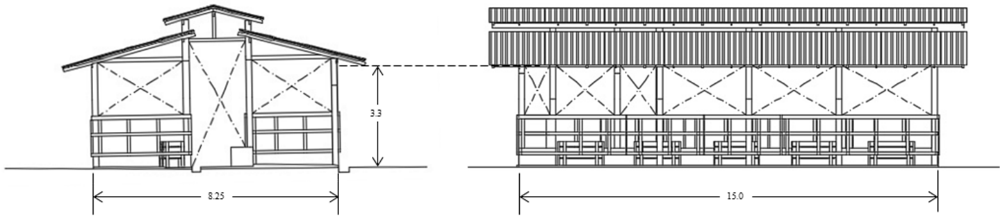


Figure 11. Floor plan before and after improvement



(a) (b)

Figure 12. Front (a) and side (b) elevations after improvement

The cattle house was in the same position with its longest side at 66°N, but the dung shed and the hay house were moved to the north-west of the cattle house to increase its inside air flow (Figure 13). In addition, the farm owners were advised to adjust their routine by rolling the nets up during the day and rolling them down in the evening when the cattle are more swarmed with insects. This adjustment can provide additional ventilation during the day.

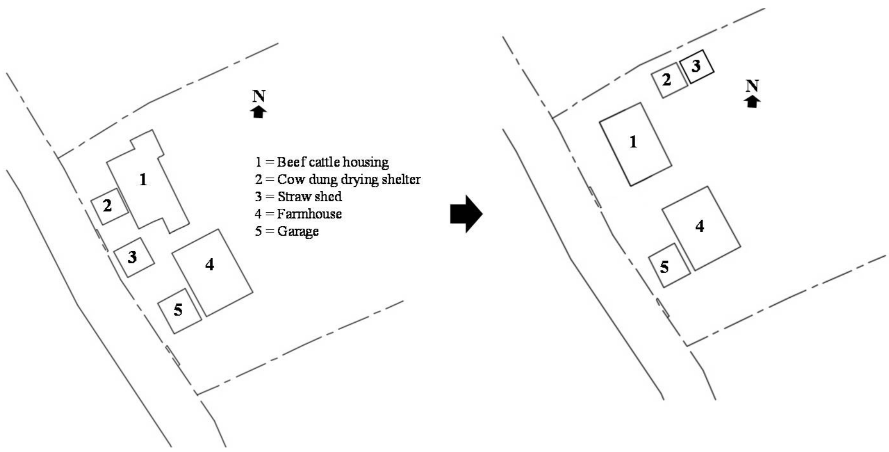


Figure 13. Farm layout before and after improvement

After the renovation, the temperatures were measured between 11 am – 4 pm for 20 days. The indoor temperature is lower than the temperature around the house, with a maximum temperature difference of 5.05°C. The indoor humidity decreases by 60–72% and the air movement inside the house also increases (Figure 14). Due to the increased house height, sunlight before 10 am can penetrate into the house, dries the house floor and reduces the humidity inside the house. As a result, the number of infesting insects and the smell are greatly reduced (Figure 15).

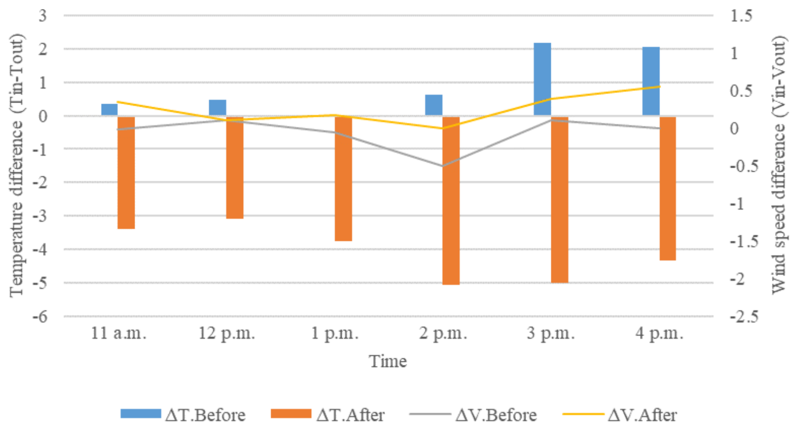


Figure 14. Differences between indoor and outdoor temperatures (T) and wind speed (V) before and after housing renovation

Figure 15. Cattle house before and after renovation

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CONCLUSIONS

On rectifying the design flaws in the case study by implementing simple passive cooling techniques and considering the constraints of smallholding farmers, the microclimate of the cattle house was considerably more comfortable. Before renovation, the heat stress level (THI) was approximately 88, which was a high-stress condition. The average temperature inside the house was 38°C, which was about 2°C higher than the outside temperature. The measured average relative humidity was 70% and the house was poorly ventilated or without airflow. After renovation the indoor temperature of the house was about 5°C lower than the outside temperature and the air velocity in the house increased to more than 1 m/s. With a drier house floor, the humidity in the house also decreased by 60–72%, with consequent reduction in annoying pests and musty smell in the house.

ACKNOWLEDGEMENTS

This work was supported by the Biodiversity-Based Economy Development Office [BEDO-NRCT 15/2561].

REFERENCES

1. V. Ricciardi, N. Ramankutty, Z. Mehrabi, L. Jarvis and B. Chookolingo, "How much of the world's food do smallholders produce?", *Glob. Food Sec.*, **2018**, *17*, 64-72.
2. B. P. Warner, C. Kuzdas, M. G. Yglesias and D. L. Childers, "Limits to adaptation to interacting global change risks among smallholder rice farmers in Northwest Costa Rica", *Glob. Environ. Change*, **2015**, *30*, 101-112.
3. B. Zamasiya, K. Nyikahadzoi and B. B. Mukamuri, "Factors influencing smallholder farmers' behavioural intention towards adaptation to climate change in transitional climatic zones: A case study of Hwedza District in Zimbabwe", *J. Environ. Manage.*, **2017**, *198*, 233-239.
4. T. Panichvejsunti, J. K. M. Kuwornu, G. P. Shivakoti, C. Grünbühel and P. Soni, "Smallholder farmers' crop combinations under different land tenure systems in Thailand: The role of flood and government policy", *Land Use Pol.*, **2018**, *72*, 129-137.
5. Y. A. Tessema, J. Joerin and A. Patt, "Climate change as a motivating factor for farm-adjustments: Rethinking the link", *Clim. Risk Manag.*, **2019**, *23*, 136-145.
6. E. Wetende, D. Olago and W. Ogara, "Perceptions of climate change variability and adaptation strategies on smallholder dairy farming systems: Insights from Siaya Sub-County of Western Kenya", *Environ. Dev.*, **2018**, *27*, 14-25.
7. R. Mandel, H. R. Whay, E. Klement and C. J. Nicol, "Environmental enrichment of dairy cows and calves in indoor housing", *J. Dairy Sci.*, **2016**, *99*, 1695-1715.
8. S. Fournel, A. N. Rousseau and B. Laberge, "Rethinking environment control strategy of confined animal housing systems through precision livestock farming", *Biosyst. Eng.*, **2017**, *155*, 96-123.
9. A. C. Falk, D. M. Weary, C. Winckler and M. A. G. von Keyserlingk, "Preference for pasture versus freestall housing by dairy cattle when stall availability indoors is reduced", *J. Dairy Sci.*, **2012**, *95,* 6409-6415.
10. M. Samer, "Adjusting dairy housing in hot climates to meet animal welfare requirements", *J. Exp. Sci.*, **2010**, *1*, 14-18.

11. M. H. Hatem, R. R. Sadek and M. Samer, "Cooling, shed height, and shed orientation affecting dairy cows microclimate", *Misr. J. Agric. Eng.*, **2004**, *22*, 714-726.
12. A. Nardone, B. Ronchi, N. Lacetera, M. S. Ranieri and U. Bernabucci, "Effects of climate changes on animal production and sustainability of livestock systems", *Livest. Sci.*, **2010**, *130*, 57-69.
13. S. Sugiono, H. Dewi and S. Rudy, "Measuring thermal stress of dairy cattle based on temperature humidity index (THI) in tropical climate", Proceedings of 3rd International Conference on Industrial Engineering and Applications, **2016**, Hong Kong, China, pp.94-98.
14. D. Renaudeau, A. Collin, S. Yahav, V. de Basilio, J. L. Gourdine and R. J. Collier, "Adaptation to hot climate and strategies to alleviate heat stress in livestock production", *Anim.*, **2012**, *6*, 707-728.
15. A. Garcia, "Dealing with heat stress in dairy cows", **2006**, https://openprairie.sdstate.edu/extension_extra/122 (Accessed: February 2019).
16. N. R. St-Pierre, B. Cobanov and G. Schnitkey, "Economic losses from heat stress by US livestock industries", *J. Dairy Sci.*, **2003**, *86*, E52-E77.
17. A. Gasparrini, Y. Guo, F. Sera, A. M. Vicedo-Cabrera, V. Huber, S. Tong, M. de S. Z. S. Coelho, P. H. N. Saldiva, E. Lavigne, P. M. Correa, N. V. Ortega, H. Kan, S. Osorio, J. Kyselý, A. Urban, J. J. K. Jaakkola, N. R. I. Ryti, M. Pascal, P. G. Goodman, A. Zeka, P. Michelozzi, M. Scortichini, M. Hashizume, Y. Honda, M. Hurtado-Diaz, J. C. Cruz, X. Seposo, H. Kim, A. Tobias, C. Iñiguez, B. Forsberg, D. O. Åström, M. S. Ragettli, Y. L. L. Guo, C. F. Wu, A. Zanobetti, J. Schwartz, M. L. Bell, T. N. Dang, D. V. Dung, C. Heaviside, S. Vardoulakis, S. Hajat, A. Haines and B. Armstrong, "Projections of temperature-related excess mortality under climate change scenarios", *Lancet Planet. Health*, **2017**, *1*, e360-e367.
18. H. Amamou, M. B. Sassi, H. Aouadi, H. Khemiri, M. Mahouachi, Y. Beckers and H. Hammami, "Climate change-related risks and adaptation strategies as perceived in dairy cattle farming systems in Tunisia", *Clim. Risk Manage.*, **2018**, *20*, 38-49.
19. M. A. Kamal, "An overview of passive cooling techniques in buildings: Design concepts and architectural interventions", *Acta Tech. Napocensis Civil Eng. Archit.*, **2012**, *55*, 84-97.
20. V. K. Firfiris, A. G. Martzopoulou and T. A. Kotsopoulos, "Passive cooling systems in livestock buildings towards energy saving: A critical review", *Energy Build.*, **2019**, *202*, Art.no.109368.
21. H. M. Taleb, "Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings", *Front. Archit. Res.*, **2014**, *3*, 154-165.
22. S. Subhashini and K. Thirumaran, "A passive design solution to enhance thermal comfort in an educational building in the warm humid climatic zone of Madurai", *J. Build. Eng.*, **2018**, *18*, 395-407.
23. Autodesk, "Autodesk® Ecotect#8482; Analysis", **2010**, http://usa.autodesk.com/adsk/servlet/pc/index?id=12602821&siteID=123112 (Accessed: March 2018).
24. X. Wang, B. S. Bjerg, C. Y. Choi, C. Zong and G. Zhang, "A review and quantitative assessment of cattle-related thermal indices", *J. Thermal Biol.*, **2018**, *77*, 24-37.
25. T. L. Mader, M. S. Davis and T. Brown-Brandl, "Environmental factors influencing heat stress in feedlot cattle", *J. Anim. Sci.*, **2006**, *84*, 712-719.

Maejo Int. J. Sci. Technol. **2022**, *16*(01), 25-39

26. S. Valtorta, "Development of microclimate modification patterns in animal husbandry", in "Applied Agrometeorology" (Ed. K. Stigter), Springer-Verlag, Heidelberg, **2010**, Ch.92.
27. Department of Livestock Development, "Information on animal farmers", **2018**, http://sdc.dld.go.th/project.html (Accessed: September 2018) (in Thai).
28. T. Manoharan, E. Vadivel, R. Venkatachalam, N. Sriram, N. Anandaraja and I. Muthuvel, "Housing management of cattle and buffalo", **2012**, http://www.agritech.tnau.ac.in/expert_system/cattlebuffalo/Housing%20Management%20of%20Cattle%20and%20 Buffalo.html (Accessed: February 2019).
29. J. I. Kindangen, L. Tondobala and M. K. Umboh, "Experimental analysis of cooling performance of spraying water automatically on the galvanized zinc-roofs", *Int. J. Eng. Technol*., **2018**, *10*, 414-422.
30. J. A. Clarke and P. P. Yaneske, "A rational approach to the harmonisation of the thermal properties of building materials", *Build. Environ.*, **2009**, *44*, 2046-2055.
31. G. Cole, "Residential passive design for temperate climates", *Environ. Design Guide*, **2011**, *iss.66*, 1-9.
32. C. Thormark, "A low energy building in a life cycle-its embodied energy, energy need for operation and recycling potential", *Build. Environ.*, **2002**, *37*, 429-435.
33. A. A. Rizk, M. S. El-Morsi and M. M. Elwan, "A review on wind-driven cross-ventilation techniques inside single rooms", *Int. J. Sci. Eng. Res.*, **2018**, *6*, 75-93.
34. M. Samer, "Effect of cowshed design and cooling strategy on welfare and productivity of dairy cows", *J. Agric. Sci. Technol.*, **2011**, *1*, 848-857.
35. K. C. K. Vijaykumar, P. S. S. Srinivasan and S. Dhandapani, "A performance of hollow clay tile (HCT) laid reinforced cement concrete (RCC) roof for tropical summer climates", *Energy Build.*, **2007**, *39*, 886-892.
36. K. M. Al-Obaidi, M. Ismail and A. M. A. Rahman, "Investigation of passive design techniques for pitched roof systems in the tropical region", *Mod. Appl. Sci.*, **2014**, *8*, 182-191.
37. P. Liberati, M. Spiga and P. Zappavigna, "Optimization of ventilated roofs for livestock housing", *Int. Commun. Heat Mass Transf.*, **2009**, *36*, 432-437.
38. Q. Roslan, S. H. Ibrahim, R. Affandi, M. N. M. Nawi and A. Baharun, "A literature review on the improvement strategies of passive design for the roofing system of the modern house in a hot and humid climate region", *Front. Archit. Res.*, **2016**, *5*, 126-133.
39. M. Santamouris, A. Synnefa, D. Kolokotsa, V. Dimitriou and K. Apostolakis, "Passive cooling of the built environment–use of innovative reflective materials to fight heat islands and decrease cooling needs", *Int. J. Low Carbon Technol.*, **2008**, *3*, 71-82.
40. A. Noelia, C. Erica and C. M. Alicia, "Urban passive cooling. Aging effects on optical properties of roof tiles", *Energy Procedia*, **2014**, *57*, 3181-3190.