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Research Article

Design and Comparative Cost Analysis of Alternative Prefabricated Beef Cattle Barns with Conventional Barn Types*

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ABSTRACT: In this study, planning, design and cost analysis of prefabricated beef cattle barns carried out. Steel mesh was used to strengthen the foundation of the structure. Galvanized-sheet material was used as the carrier and cover material, and shaped like a trapezoid cross-section. The barns, which are planned in the form of tunnel cross-section and tie-stalls type, are designed for 10, 20 and 30-cattle to be particularly suitable for family enterprises. Polyurethane (PU) foam and extruded polystyrene sandwich panel (XSP) were used to provide heat and sound insulation. Cost analysis of the galvanized-sheet barns was compared with the barns constructed by the traditional production method. After analyses, we found that as the number of animals increased, barn cost per animal decreased. The cost reduction rates in the PU foam insulated galvanized-sheet barn were 30.1%, 32.7% and 30.6% for the 10, 20 and 30-cattle respectively. These values were 24.9%, 27.8% and 25.5% for the sandwich panel insulated galvanized-sheet barn. The most economical combination was the polyurethane foam insulation of galvanized sheets. Galvanized-sheet barns are technically sufficient, and economically advantageous than the conventional ones, so it can be recommended to both newly established enterprises and enterprises that want to improve their old barns.

Keywords: Prefabricated barns, Tie-stalls type, Cost analysis, Galvanized sheet, Polyurethane foam

Yaygın Barınak Türlerine Alternatif Olabilecek Prefabrik Barınakların Tasarımı ve Karşılaştırmalı Maliyet Analizi

ÖZ: Bu çalışmada, prefabrik barınak yapı elemanlarının planlaması ve tasarımı yapılmış, geleneksel yöntemle üretilen barınak türü ile karşılaştırmalı maliyet analizi gerçekleştirilmiştir. Yapının temelinde çelik hasır kullanılmıştır. Taşıyıcı ve örtü malzemesi olarak galvaniz sac malzeme kullanılmıştır. Sac metalin dayanımını artırmak için malzeme trapez verilmiştir. Tünel kesitli ve bağlı duraklı tipte planlanan barınaklar, özellikle aile işletmeleri için uygun olacak şekilde 10, 20 ve 30 başlık tasarlanmıştır. Galvaniz sac malzemede ısı ve ses yalıtımı sağlamak için poliüretan (PU) köpük ve ekstrüdepolistiren sandviç panel (XSP) kullanılmıştır. Tasarlanan galvanizli sac barınakların maliyeti, geleneksel yolla üretilenlerle karşılaştırılmıştır. Analizler sonucunda hayvan sayısı arttıkça hayvan başına barınak maliyetinin düştüğünü görülmüştür. PU köpük ve XSP izoleli galvaniz sac malzemeden yapılan barınaklarının geleneksel yöntemle üretilenlere göre daha ekonomik olduğu görülmüştür. Poliüretan köpük yalıtımlı galvanizli sac barınakta maliyet düşme oranları 10, 20 ve 30 başlıklar için sırasıyla % 30.1, % 32.7 ve % 30.6 olmuştur. Bu değerler sandviç panel yalıtımlı barınak için % 24.9, % 27.8 ve % 25.5 olarak gerçekleşmiştir. En ekonomik barınak türü galvanizli sac ve poliüretan köpük yalıtım birleşimi olmuştur. Galvanizli saclardan yapılan prefabrik barınaklar teknik olarak yeterli ve geleneksel olanlara göre ekonomik olarak avantajlı olduğundan hem yeni kurulan işletmelere hem de eski barınaklarını iyileştirmek isteyen işletmelere tavsiye edilebilir.

Anahtar Kelimeler: Prefabrik barınak, Bağlı-duraklı tip, Maliyet analizi, Galvanizli çelik, Poliüretan köpük

INTRODUCTION

The requirement of nutrition is increasing in parallel with the rise of the world population. Animal products are the most important source of protein and indispensable for a balanced diet program. Owing to

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the increasing demand for animal products and the intensive livestock production system, the importance of animal welfare was mentioned more in the literature (Broom, 1991; Bracke and Hopster, 2006; Er and Kuslu, 2019; 2020).

Climate factors are one of the most important issues that are considered in the construction of barns because they affect animals in many ways. The most important environmental conditions which determine the animal yield are temperature, relative humidity, the composition of barn air, ventilation capacity, airflow rate, and lighting. However, the climatic conditions of the region and the economic limits of the enterprise should be taken into consideration while planning (Ekmekyapar, 2001; Turhan, 2016). The following objectives are expected to be achieved in the construction of the barns; to protect the animals from unfavorable weather conditions, to create healthy and hygienic ambiance, to realize an efficient production environment, and to provide economy from time and labor.

Temperature is one of the most important environmental conditions within the barns. It is the criterion of providing the comfort of the animals and it is very important for the execution of physiological functions. Cattle have the highest efficiency with minimum feed consumption in comfort zone temperature values. (Brom, 1991; Uzal, 2004; Kocaman et al., 2007; Lateef et al., 2008; Usta 2011; Dawkins, 2016). In terms of yield, the comfort zone temperature is reported to be 10-20 ° C for cattle weighing up to 150 kg and 0-20°C for cattle weighing up to 800 kg (Trampler, 1989).

Different values have been suggested in the literature on the appropriate relative humidity values in barns. It is stated by Ekmekyapar (2001) and Şirin and Kocaman (2016) that the relative humidity range of barns can be between 60% and 75% and this value can be increased up to 85% in a very cold region. İçöz (1998) suggested that the appropriate relative humidity should be between 50-75%. Wathes et al. (1983) argued the relative humidity of animals in terms of their health and body temperature balancing mechanisms should be between 40-90%.

The polluted air in the barns environment, harmful gas and unwanted odors should be replaced by fresh air. The ventilation rate is given by Noton (1982) such as 30-75 m^3/h for 100kg and 400 kg live weight respectively. The windows in the barns allow both the lighting of the interior and the supply of fresh air into the barn. The ratio of window area to floor area in closed barns should be at least 3.5%, 5%, and 10% in the cold, warm, and hot climate zones respectively (Ekmekyapar, 2001).

The connected stalls are one of the different barn types in terms of planning. In such barns, resting, feeding and watering works of the cattle are carried out at special stands reserved for them. The most important reasons for preferring beef cattle breeding in this type of barns are to eliminate the negative effect of possible weather changes on cattle, to protect the cattle from the mud effects, and to prevent feed losses via feeding easily the animals (Erbatur, 2010). If the number of animals is less than 12, these type barns are planned as a single row otherwise, it is designed as a double row (Ekmekyapar, 2001).

Prefabrication is defined as the process of assembling the construction elements produced in factories in a controlled manner to each other in the construction site environment and the structures produced with this system are called prefabricated structures (Türker, 1998; Gürer, 2008). The galvanized sheet that is used in the prefabricated system's structural elements is a material which is obtained by coating the sheet with chrome and zinc and produced by hot dipping method international standards (TS, 822). The galvanized sheets can hold the paint on it, shape it easily, and can be apply practically. These properties such as long life and fire resistance provide the advantage from the other materials. Due to the coding of galvanize material, this material is more resistant to corrosion and external factors (Karakaş, 2013).

In the barns, thermal insulation processes should apply to prevent hot or cold air from entering or leaving the building by creating thermal bridges. Generally, thermal insulation materials are used such as; glass wool, rock wool, sandwich panels from expanded polystyrene foam (EPS), extruded polystyrene foam (XPS), polyurethane (PU) foam (Hegger et al., 2006). XPS is an insulation material that consists of disconnected cells and can be produced in thicknesses between 20mm and 120mm The thermal conductivity coefficient of this material varies between 0.030 and 0.040 w/mK. Due to its strength in the freeze-thaw cycle, the durability of the material lasts throughout the life of the building. The thermal conductivity value for spray PU varies between 0.017 - 0.025 w/mK, and its volume increases rapidly after it is sprayed. It is resistant to ultraviolet rays. It does not move after being sprayed, and can also be used inside or outside structures. It provides high resistance, flexibility, and non-slip surfaces against abrasion.

Agriculture and animal husbandry are the source of the main livelihood for the people living in the rural area of Erzurum province. Cereals and forage crops are grown in dry farmland, while potato, sugar beet, silage maize, and sunflower are grown in irrigated areas. Vetch, sainfoin, and alfalfa are some of the most cultivated forage crops. More than 60% of the land of the agricultural zone in Erzurum is meadow-pasture land. Therefore, livestock farming is

one of the main activities in rural areas (Kuslu, 2008). The agricultural economy of Erzurum province consists of livestock farming around 64%, crop farming 36% and cattle farming 5%. (TSI, 2017).

In Erzurum conditions, the size of the herd that should be kept for sustainable beef cattle enterprises is varied in the different corporations. For example, these numbers are accepted as 25 cattle by banks who financed the farmers, and 40 cattle by agricultural institutions. However, there are fewer cattle in family-type enterprises today in Erzurum. (CAE, 2018).

In this study, beef cattle barn plans for cold climate such as Erzurum conditions have been developed and compared with traditional barns by cost analysis. Developed barns are suitable for 10, 20 and 30 cattle. They include tie-stall closed barns types, produced from galvanized sheet material, prefabricated, PU and XPS insulated properties.

MATERIAL AND METHOD

In this study, the Erzurum region was chosen as the research area because of its large beef cattle growth potential. In terms of geographical location, Erzurum province lies between 40°-15" and 42°-35" east longitudes and 40°-57" and 39°-10" northern latitudes. Erzurum province remains mostly dry and warm in summers but cold and snowy in winters. The long period (from 1950 to 2018) average annual temperature is 5.7°C. The coldest month is January with an average of -9.2°C and the hottest month is August with 19.5°C. The average annual rainfall is 432mm, the highest rainfall is in May with 73.8mm and the least rainfall is in August with 17.7mm. The average annual relative humidity was determined as 64% (TSMS, 2018).

In the traditional method, the foundation and bearing elements are made from reinforced concrete. In this production, brick, interior and exterior plaster were used on the wall and wood was used on the roof truss elements. The foundation of the prefabricated barn is constructed from reinforced concrete by using steel mesh. The galvanized steel sheet has been strengthened by trapezoidal shape and used as the main building element in tunnel form. XPS sandwich panel and spray PU foam were used to provide sound and heat insulation of the galvanized sheet. XPS and spray PU foam are widely used for insulation because they do not absorb water and are not affected by moisture and their thermal insulation performance do not change over time. Because of these properties, they were preferred in this research.

In the calculations, the temperature inside the barn was 10°C and relative humidity was taken as 80% for the winter season. As the average outside temperature and relative humidity for the project the average low-temperature and relative humidity values of the coldest month have taken. The principles were taken into consideration in the calculations regarding ventilation for summer and warm seasons. Ventilation openings were made base on temperature balance and it was checked whether the values found provide moisture balance. The average weight of cattle has been assumed to be 500kg (Wathes et al., 1983; Ekmekyapar 2001; FAO, 2011; Yanık and Okuroglu, 2017).

The Turkish Standards such as TS 822 (2019), TS 498 (1997), and TS EN 10346 (2015) were used related to calculations of prefabricated buildings with galvanized sheet construction material. The cost calculations of the barns were made and compared with the costs of the traditional tie-stall barns types according to the same year data. The cost calculations of barns were performed concerning the Republic of Turkey Ministry of Environment and Urbanism, the companies in the construction field, and the market price list (unit cost) and calculated amount of material (amount). The following equation is used in the cost calculation.

$$total\ cost = amount \times unit\ cost \quad (1)$$

Dimension calculations of the structural elements of the barn have been made with the help of the equations (Equation 2, 3, 4, 5) given below.

$$N = A \times k_n \times \mathrm{n} \quad (2)$$

where N= total amount of water vapor emitted by cattle (g), A= body surface area of a cattle (m^2), k_n= the amount of water vapor emitted from the body surface area of 1 m^2 at 10°C (g/m^2h) and n= the number of cattle in the barn,

$$Q = A \times V \quad (3)$$

Where, Q= ventilation rate required (m^3/h), A= the total area of the air outlet (or inlet) openings (m^2) and V= airflow velocity (m/s) calculated from the following equation,

$$V = 1{,}8 * \sqrt{\frac{H(ti-td)}{273+td}} \quad (4)$$

Where H= effective flue height (m), ti= indoor temperature (°C), td= outdoor temperature (°C)

$$n = \frac{A}{a} \quad (5)$$

Where, n= number of the chimney (pcs), A= the total area of the air outlet openings (m^2) and a= a chimney area (m^2)

$$w = \frac{A}{a} \quad (6)$$

Where w= number of window (pcs), A= the total area of the window openings (m^2) and a= a window area (m^2)

According to the Regulation of Agricultural and Rural Development Support Institution, the window area should be at least 5% of the barn floor area. It was checked whether the values calculated by the equations appropriate this rule.

RESULTS AND DISCUSSION

Some parameters calculated for 10, 20 and 30 head beef cattle barns are given in Table 1. These dimensions and admissions are the same for all barn combinations.

Table 1. Some parameters for 10, 20 and 30 head beef cattle barns

Admissions and calculations	10-cattle	20-cattle	30-cattle
Barn height (m)	4	4	4
Barn width (m)	7	7	10
Barn length (m)	18	30	24
Ventilation rate (kg/h)	949.5	1898.9	2848.2
Window number(pcs)	5	8	8
Window area (m^2)	6.3	10.5	12
Chimney number (pcs)	2	3	5
Special shed area (m^2)	4.7	4.7	7.7
Feed storage area (m^2)	4.7	4.7	7.7

As seen in Table 1, barn height is 4m in all barn combinations. For 10-cattle and 20-cattle barns, the barn width, special shed, and feed storage area have the same values. The window number is equal to 20-cattle and 30-cattle barns, but window area values are different.

The general view of the designed galvanized sheet shelter is given in Figure 1. Figure 2a shows a floor plan and a cross-sectional view of the 10-cattle barn. Figure 2b shows the floor plan of the 20-cattle barn. The cross-sectional view of this barn is the same as in Figure 2a. Figure 2c shows the floor plan and cross-sectional view of the 30-cattle barn.

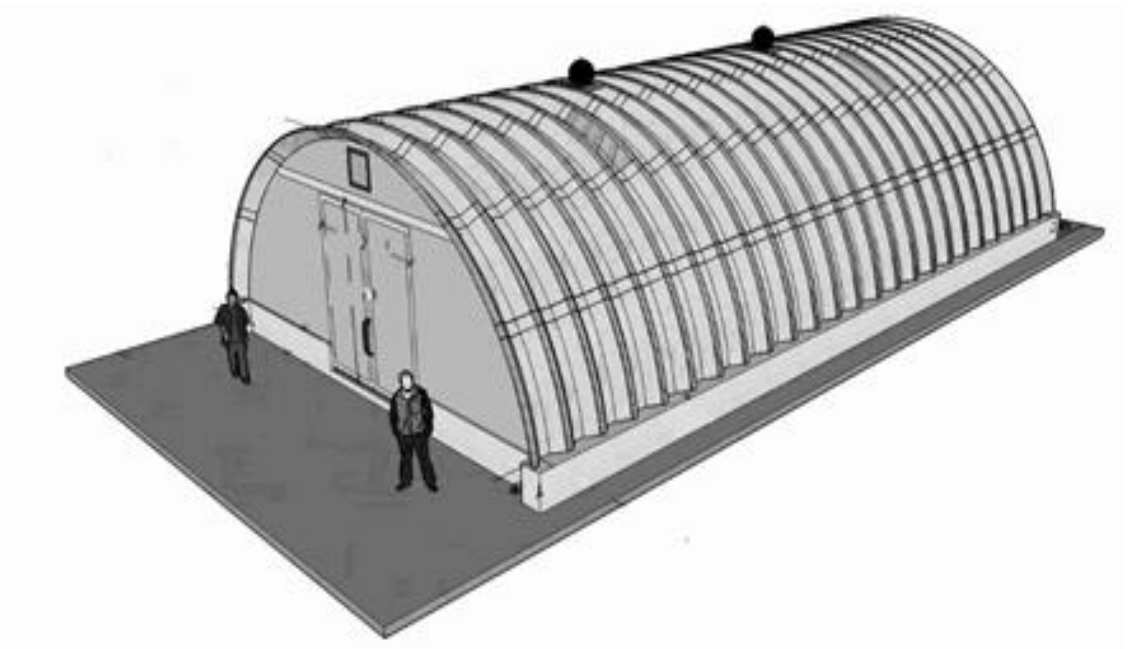
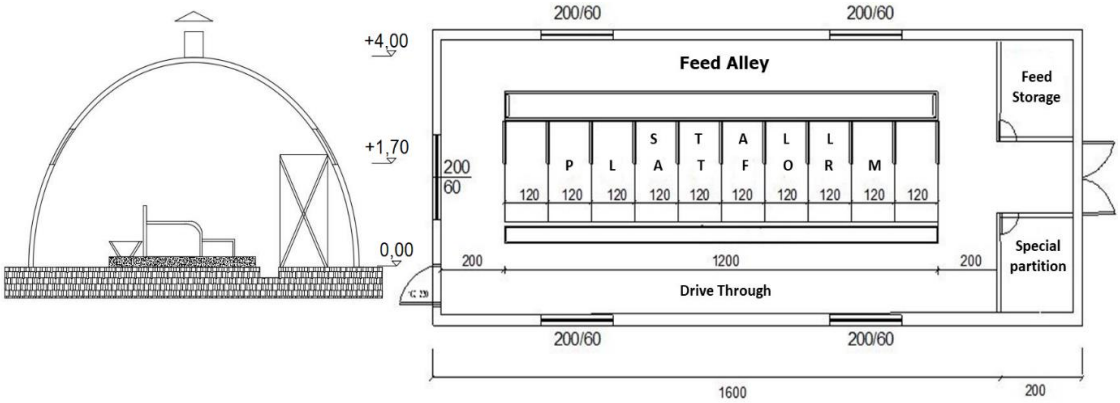
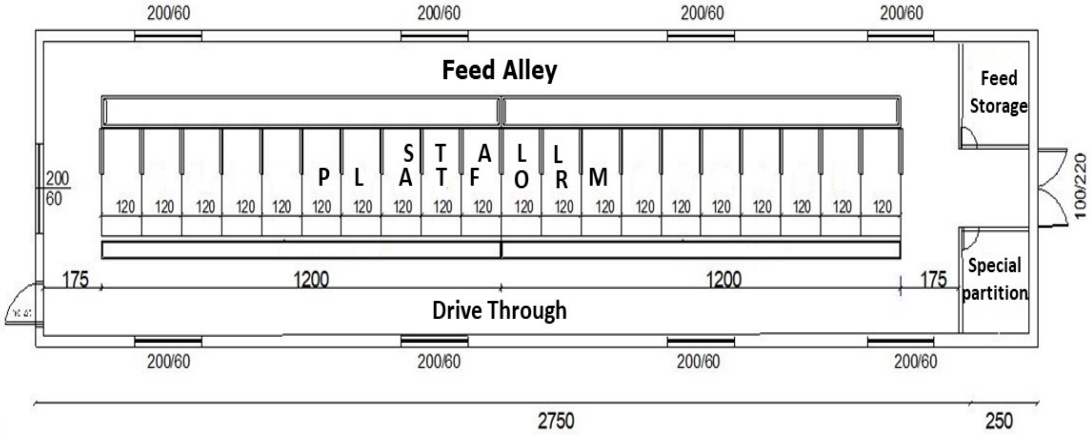


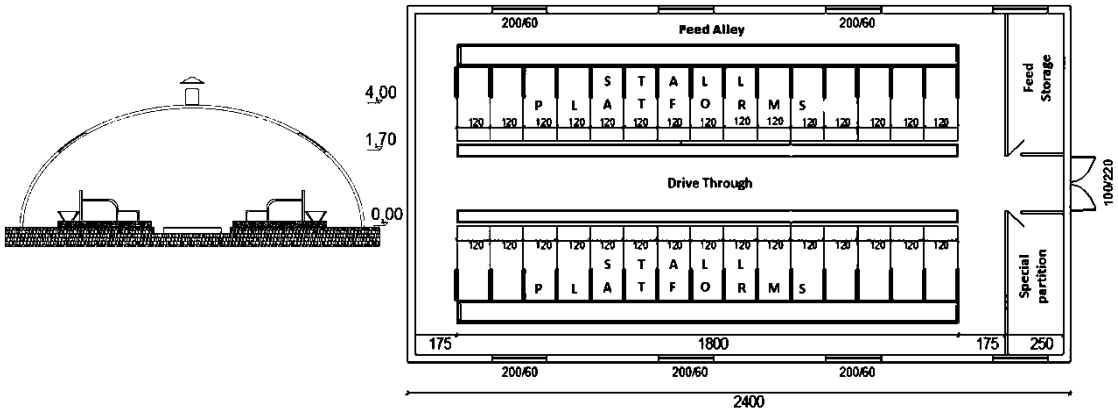
Figure 1. General view of the designed galvanized sheet beef cattle barn



(a)



(b)



(c)

Figure 2. Floor plan and sectional views of galvanized sheet and tie-stall barns designed for different animal capacity: 10-cattle (a), 20-cattle (b) and 30-cattle (c)

The 10-cattle and 20-cattle barn combinations are single-row, and the 30-cattle barn combination is two-row. The most important reason for choosing it in this way is that it provides economical use of the material and floor area. The importance of this situation has also been emphasized by Noton (1982), Ekmekyapar (2001), Aslan and Seyfi (2015), and Şirin and Kocaman (2016). The calculation steps for prefabricated barn combinations are given in Table 2.

The costs of different barns of which have tie-stall and closed properties and costs per animal values are shown in Table 3.

Table 2. Quantity survey of prefabricated barns with galvanized sheet material / spray polyurethane foam and sandwich panel insulated material*

Work number	Type of work (unit)	Amount			Unit Cost**	Total Cost ($)		
1	Earth Excavation (m^3)	10 Head	20 Head	30 Head		10 Head	20 Head	30 Head
2	Stone Blockage m^3	72	115.2	124.8	1.1	75.8	121.3	131.4
3	the Grabeto (m^3)	36	57.6	62.4	10.3	371.2	594.0	643.5
4	Base Concrete (m^3)	18	28.8	31.2	38.2	688.2	1101.2	1192.9
5	Wire mesh (kg/piece)	54	86.4	93.6	42.6	2302.9	3684.7	3991.8
6	Galvanized sheet side surface (piece)	16.75	26.79	29	14.7	246.3	394.0	426.5
7	Front and rear facade surface (m^2)	6	10	8	1623.5	9741.2	16235.3	22823.5
8	Window (piece)	43.96	43.96	62.8	21.2	930.9	930.9	1329.9
9	Ventilation chimney (piece)	5	8	8	17.6	88.2	141.2	141.2
10	Ventilation fan (piece)	2	3	5	94.1	188.2	282.4	470.6
11	**Insulation with spray polyurethane foam (m^2)*** **	2	3	4	416.5	832.9	1249.4	1665.9
12	**Sandwich panel insulation with filling material(m^2)*** **	**192.55**	**304.31**	**336.84**	**8.8**	**1699.0**	**2685.1**	**2972.1**
		192.55	**304.31**	**336.84**	**15.4**	**2973.2**	**4698.9**	**5201.2**

*Quantity surveys were calculated according to the year of 2018 unit costs. (At the beginning of this year, 1 Dollar was equal to 3.4 Turkish Liras)

** The cost calculations were performed concerning the Republic of Turkey Ministry of Environment and Urbanism, the companies in the construction field, and the market price list.

*** One of these isolation methods will be chosen according to the barn combinations.

Table 3. The costs of different barn combinations

	Conventional type			Galvanized sheet + PU			Galvanized sheet + XPS		
Barn combination	**10-cattle**	**20-cattle**	**30-cattle**	**10-cattle**	**20-cattle**	**30-cattle**	**10-cattle**	**20-cattle**	**30-cattle**
Cost ($)	24493	40638	43790	17165.0	27419.4	35789.2	18439.2	29433.2	38018.3
Cost per animal ($)	2449.3	2031.9	1459.7	1716.5	2741.9	3578.9	1843.9	2943.3	3801.8

After the analyses, it was found that prefabricated barns are more economical than conventional types (Figure 3).

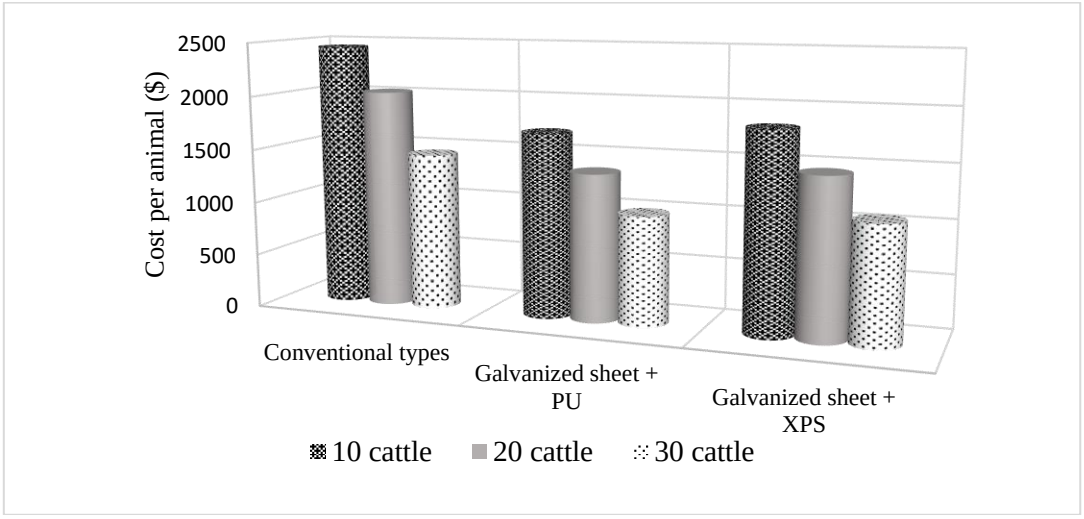


Figure 3. Different barn combinations and cost per animal ($)

Ferrer et al. (2007) suggested that the cost of prefabricated buildings should be decreased as compared to traditionally produced structures due to the reduction in structural dimensions. Prefabricated buildings are widely used because of their advantages such as having different usage areas, strength, lightness, new appearance and low construction cost (Dong et al., 2006; Dong et al., 2012). Arslan et al. (2006) stated that prefabricated buildings have sufficient to absorb the earthquake shocks due to the rigidity and ductility properties of the structures than normal reinforced concrete structures. It has been common in recent years that some or all of the farm buildings consist of prefabricated elements (Aslan and Seyfi, 2015; İnci et al., 2019).

The cost reduction rates in the polyurethane foam insulated galvanized sheet barn were 30.1%, 32.7% and 30.6% for the 10, 20 and 30 heads respectively. These values were 24.9%, 27.8% and 25.5% for the sandwich panel insulated galvanized sheet barn. At the end of the research, it was seen that the cost of stables per unit animal decreased as the number of animals increased (Figure 3). In a study conducted by Er and Kuslu (2020), it was found that prefabricated barns produced with light concrete are more economical than conventional type barns.

CONCLUSION

To increase the income levels of the agricultural enterprises in the study area, livestock enterprises should be based on more modern and economic principles. Also, it may be planed more economical structures by modernizing old type barns that cause low productivity and diseases. Animal production will have advanced with the design and application of barns that are more economically convenient, modern, easily built, reduce the workload of the workers, and create comfortable environments for animals. Prefabricated barns fulfill many of the features listed above. In prefabricated systems, construction time is shortened compared to traditional systems and can be produced in series. Prefabricated barn systems directly affect the national economy due to the low cost of the project as well as a qualified production. It also contributes indirectly in terms of taking part in the development of animal production. It is important to have more modern and cost-effective structure options to increase the income levels of livestock enterprises in rural areas. This study finds that the galvanized sheet

increases the strength via trapezoidal shape, insulated with PU foam, and XPS sandwich panel that not only sufficient as required by the need but also it is economically viable for the engineering purposes. This study suggested that these prefabricated structures may be taken into consideration particularly, in the structural modernization of family-type such as; animal husbandry enterprises or for the establishment of new enterprises. These buildings may produce resilience and practically sufficient properties in terms of providing hygiene and comfort for the employees and animals.

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Statement of Conflict of Interest

The authors should declare that they are no conflict of interest.

Authors' Contributions

YK defined and edited the research, HE worked on the preparation of Figures 1, 2, and Table 3. All authors contributed to the writing of the article and took part in the process of publication of the article and read and approved it.

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