Comparison of Energy Needed to Heat Greenhouses and Insulated Frame Buildings Used in Aquaculture[1]

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Introduction

A water recycling aquacultural production system must be housed in a building to be effective. A typical water recycling aquacultural production system consists of production tanks, a pump, a filtering system, a temperature control system, a heating system and/or cooling system, the plumbing and valves necessary to control the flow of the water, a source of water and housing for the system. Locating production inside a building offers several advantages such as stable water conditions, protection from predators, the ability to control photoperiod, security from vandalism, and better overall management. Because of the high stocking densities in closed systems, it is necessary to maintain close control of several water quality factors. The system's temperature is an important parameter which must be maintained at a stable value. Fish grow fastest when maintained within a narrow temperature zone. Also, heating energy is saved by maintaining stable temperatures. A wide variety of types of structures can be used for ornamental fish production. These structures range from pond covers and plastic covered greenhouse structures to insulated frame buildings.

Greenhouse Structures

Inexpensive plastic covered greenhouse structures of the type used by the horticulture industry for plant production are frequently used to house closed recycling aquaculture systems. Aquacultural producers do not commonly use the more expensive glass greenhouses used by some of the plant production industry. A plastic covered greenhouse structure is easy to construct on almost any site and has a low initial cost. Building material costs for the structure can be as low as $1 per square foot, but plastic covered greenhouse structures have the disadvantages of a short lifetime, of requiring regular maintenance and of requiring a cooling system during the summer. In addition, greenhouse structures are difficult and expensive to heat during cold weather.

Frame Structures

Low-cost wood or metal frame structures covered with siding material offer an alternative to plastic covered greenhouse structures. Building costs for this type of structure can be as low as $4 to $6 per square foot. Construction costs for wood or metal frame buildings are greater than for greenhouse type structures, making the initial cost higher, but this type of structure also has a much longer expected lifetime than a greenhouse structure. The best grades of greenhouse plastic films will last for only three years in Florida unless they are covered with paint or shadecloth. The plastic films are broken down by the high ultraviolet levels in Florida summer sunlight. Even when painted or covered with shade cloth, the plastic film will seldom last over five years. A well- constructed wood or metal frame

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building has an expected lifetime of over twenty years. The frames of these buildings can be covered with a variety of siding materials including metal and wood. Plastic sheet material can be used to cover frame buildings if it has been treated to resist ultraviolet degradation. Wood or metal frame buildings also are better suited to withstand the high wind loads that can be expected periodically in Florida. In addition, insulation is easy to install in frame structures. Insulated structures cost less to heat and are easier to keep at stable temperatures.

Comparison of Structures

A greenhouse does offer more control over the environment than an open pond, but it offers less control than a frame building. Greenhouse structures are designed for plant production and compromise between providing an enclosure for the plants and letting in the maximum amount of light for plant production. The high light levels needed for plant production are not needed for ornamental fish production and may promote algae growth or cause overheating of the structure during the summer. An unventilated greenhouse in Florida will frequently reach temperatures well over 100°F during the summer, and in some cases temperatures rise as high as 130°F to 140°F. Ventilation and cooling systems must be installed to keep water temperatures low and for workers to be able to function in this type of building during the summer. During winter conditions, a greenhouse structure does offer some protection from cold temperatures, but greenhouses are expensive to heat because of the low insulation value of their plastic walls.

A wood frame or metal building can be designed specifically to house an aquacultural facility and make managing the system easier. The floorplans of framebuildings offer more flexibility in the arrangement of tanks and plumbing than those of greenhouses. The higher strength of the frame makes it easier to support suspended plumbing and electrical work for better routing and safer installation. It is easier to construct separate rooms to house filters, feed storage, and sensitive equipment. The higher initial costs of a frame building are offset by the longer building life, reduction in energy costs, and improved working conditions. Insulation is easily installed in the walls of frame buildings to reduce the amount of energy needed to heat the building during cold weather.

Energy Needed for Heating

Either type of building can be successfully used in aquaculture. Each type of construction has its advantages. A greenhouse structure is advantageous when low initial cost is required or when it is planned for a building to be in use for only a year or two. A wood or metal frame building has advantages when a permanent building is planned and operating costs are most important. The main difference in operating costs is caused by the energy used to heat the structure and water during cold weather. The energy lost through the walls of a structure during cold weather must be replaced by the heating system in order to maintain a stable temperature inside a structure. The amount of energy that must be supplied is related to the difference between inside and outside temperatures and the thermal resistance or "R" value of the building's roof and walls. The amount of energy required to heat a building is calculated from the equation in Figure 1.

$$Q = A \cdot \Delta T / R$$ where:

A = Area, ft^2

ΔT = Temperature difference between inside and outside, °F

R = Thermal resistance, ft^2 - °F - h/BTU

Figure 1.

Plastic greenhouses can be covered with either polyethylene film or fiberglass sheet, or any combination of film and sheet. A sheet of fiberglass or a single layer of polyethylene film has an R value of 0.85. Most plastic greenhouses are constructed using a type of construction called double poly consisting of two layers of polyethylene. By inflating the space between the two layers of film, the R value is increased about 50% to 1.25.

Frame buildings can be covered with a wide variety of coverings ranging from plastic sheets to wooden and metal siding. The coverings seldom add significantly to the thermal resistance of a building. The R value of a sheet of metal is the same as that for a sheet of plastic. However, insulating materials are easily installed in the walls of frame buildings, and the thermal resistance of the building can be increased to very high values. However, extremely high levels of insulation are usually not economical and R-11 will normally be adequate. The recommended R value used for frame buildings used for aquacultural production is R-11.

Cost Comparison

To illustrate the difference in costs for a typical greenhouse structure and the same size frame building used for aquacultural production, consider a structure 30 feet wide and 100 feet long with an eave height of 10 feet. Assuming that

the same number of tanks and the same operating equipment are located in both structures, the differences in costs will be in the initial costs, maintenance costs, depreciation, and energy costs.

The estimated initial cost of the 3,000 square foot greenhouse structure at $1 a square foot is $3000. The estimated initial cost of an uninsulated frame buildinginsulated with R-11 insulation at $5 per square foot is $15,000. About $2,500 of the cost of the frame building is spent on purchase and installation of the R-11 insulation. Note that both these estimates are for the building only and do not include foundation and flooring or any of the production equipment. Both buildings have the same total surface area of about 5,800 square feet and are assumed to be located with the same orientation to the sun and in the same general area away from any nearby buildings.

The amount of energy used to heat a building depends on the desired inside temperature, the surface area of the building, the thermal resistance of the material covering the building and the outside weather conditions. Typical aquacultural systems operate at temperatures in the range of 75°F to 80°F. The following comparisons are between a plastic greenhouse structure covered with a single layer of polyethylene film (R = 0.85), a plastic greenhouse structure covered with two inflated layers of polyethylene film (R = 1.25) and a frame building covered with metal siding and metal roofing material with the walls and ceiling insulated with R-11 insulation (R = 11). The weather conditions assumed are for central and south Florida. Hourly average temperatures were extracted from 11 years of records for 1980 to 1990 from this area of Florida. The total number of degree-hours below 75°F and 80°F was calculated from the set of hourly average temperatures and, for an average one year period, was 54,000 and 82,000, respectively. The energy use for a building during a year is calculated using the estimate of the total degree-hours for one year with Equation 1, the building surface area and the R value for the building material. The results of this calculation for the three building types and inside temperatures of 75°F and 80°F are shown in Table 1.

Energy used to heat a structure is usually provided by the combustion of some fuel on site, but energy can be provided by electricity or in some cases alternative energy sources such as solar or geothermal can be used. The main factor used to compare different types of fuel is usually the cost of the fuel per unit of energy delivered. Table 2 shows the energy content of several common fuels. The cost of heating a structure depends on the fuel's energy content and on the cost of the fuel. Table 3 compares the number of BTUs that a dollar will buy for electricity, propane and #2 fuel oil. The values for propane and #2 fuel oil account for a 70% combustion efficiency when used for heating.

Annual costs for heating each of the three building types are shown in Table 4, based on the energy cost of $1.25 per gallon for propane. The cost of fuel varies with fuel type and with time. Fossil fuels typically range in cost from less than $1 per gallon for fuel oils to greater than $1 per gallon for propane and gasoline. The most expensive source of energy for heating is electricity.

The results shown in Table 4 depend on the values assumed in all the previous calculations and on weather conditions in future years. However, if the higher initial cost of a frame building can be afforded, the savings in energy consumption can result in significant savings over the lifetime of a structure housing a closed recycling aquaculture system.

Table 1. Annual energy use.

Building Type	Thermal Resistance, R (ft^2-°F-h/BTU)	Annual Energy Use for Heating for 75°F Inside Temperature	Annual Energy Use for Heating for 80°F Inside Temperature
Greenhouse Covered with One Layer of Plastic Film	0.85	388,000,000	560,000,000
Greenhouse Covered with Two Inflated Layers of Plastic Film	1.25	251,000,000	380,000,000
Insulated Frame Building	11.00	28,000,000	43,000,000

Table 2. Energy contents of electricity and common fossil fuels.

Fuel	Energy Content
Propane	85,000 BTU/gal
#2 Fuel Oil	141,000 BTU/gal
Electricity	3,413 BTU/kwh
Natural Gas	100,000 BTU/therm

Table 3. Fuel and electricity energy costs.

Electricity	Propane	#2 Fuel Oil	Natural Gas
34,100 BTU/$	47,600 BTU/$	98,700 BTU/$	133,300 BTU/$
$0.10/kwh	$1.25/gal	$1.00/gal	$0.75/therm

Table 4. Annual energy costs.

Building Type	Annual Cost for Heating for 75°F Inside Temperature	Annual Cost for Heating for 80°F Inside Temperature
Greenhouse Covered with One Layer of Plastic Film	$8,100	$11,700
Greenhouse Covered with Two Inflated Layers of Plastic Film	$5,200	$7,900
Insulated Frame Building	$540	$900