North Central Regional
Aquaculture Center

Fact Sheet Series

Buildings for Aquaculture Operations

Figure 1. A warehouse/factory converted to Tilapia RAS production.

Figure 2. Partitioning a section of warehouse for marine shrimp production.

Introduction

Over the past 20 years, new aquaculture production in the Midwest has shifted from outdoor pond production to indoor Recirculating Aquaculture Systems (RAS). Research and development of these systems have focused on making fish rearing more efficient but have spent little effort on the buildings in which these systems are housed. A recent survey of five existing aquaculture operations in the Midwest attempted to fill the knowledge gap in order to determine the useful life of these buildings, and to evaluate energy efficiencies, structural layouts, and well-being of workers.

Historically, building recommendations for a variety of livestock species were obtained from the Midwest Plan Service (MWPS), which developed building designs and handbooks based on engineering principles applicable to each species (www-mwps.sws.iastate.edu). Aquaculture (fish) have not been included in these publications as aquaculture operations have several challenging environmental conditions that need special consideration, including high temperature and high humidity for some species.

Building new or renovating old?

Building or renovating a structure for aquacultural use is only one part of a successful operation. A complete business plan, including marketing, must be completed prior to any construction. In the case of renovation, the existing building dimensions may not fit the needs of the business and so construction might be phased in for a smaller initial operation, or new construction/additions to an existing structure might be required to meet market demand.

The majority of this publication is concerned with engineering; however, system requirements, fish movement, storage, etc. must be considered prior to construction so the end product is not only environmentally sound but also meets the needs of the rearing processes. Some potential considerations include office space; restroom/showers; space for feed and equipment storage; dimensions of systems and tanks; head height of equipment; door widths to get equipment and tanks in and product out; space for the use of equipment such as a forklifts and skid steers; fish pumps or graders; drainage from tanks, floors, and its disposal; and electrical supply.

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Basic principles and considerations

The sites selected for study were diverse for several reasons. Currently, there is no standard indoor aquaculture system or building, but rather, multiple species, systems, and building types. Also, the choice of whether to rehabilitate an existing farm building or warehouse or build new must be considered on a case-by-case basis. No matter the type of building or species raised, there are basic principles to consider in terms of both building construction and management of environmental conditions. The recommendations in this publication are based on good engineering principles and data collected from existing producers.

Figure 3. An electric exhaust fan for ventilation. Note the spray-on closed cell foam on the wall.

As stated, there is no standard aquaculture building in existence. However, there are numerous components that must be considered for a structure to be successful. Farms studied included two facilities in warehouses with mostly steel superstructures, rehabilitated farm buildings formerly used for livestock, and new construction that was either purpose-built or a pole building modified for use with aquaculture. Buildings must meet local building codes and also meet anticipated limits for dead, snow, wind, floor, suspended, and stored materials loads. For aquaculture buildings, the major considerations beyond building codes include but are not limited to insulation (R values), vapor barriers, interior sheathing, and flooring.

Building insulation

Maintaining temperature throughout the year is critical to the marketing success of an operation, allowing consistent year-round production. Sizes and types of heating systems will be discussed, but maintaining a constant temperature has a lot to do with the materials used in construction and their insulation or R-values. All structural materials have R-values, many of which can be found in the "MWPS Structures and Environment Handbook" (www-mwps.sws.iastate.edu/catalog/construction-farm/structures-and-environment-handbook).

The R-value of a wall is the sum of the R-values of the individual components because heat is forced to flow through each wall layer. For example, a one-layer concrete block warehouse wall has an R-value of 2 hr-ft^2-°F/Btu. Installing one inch of polyisocyanurate foam board (R=7.2 hr-ft^2-°F/Btu) on one side of the concrete blocks increases the R-value to 9.2 hr-ft^2-°F/Btu for the two-layer wall. The heat loss per square foot of wall is calculated by dividing the temperature difference across the wall by the overall wall R-value. For example, if the inside and outside surface temperatures were 90°F and -2°F, then the heat loss would be 92°F divided by 9.2 hr-ft^2-°F/Btu = 10 Btu/hr-ft^2. The total heat loss of 100 ft^2 of this wall would be 10 x 100 = 1,000 Btu/hr.

For buildings being renovated there is generally little that can be done to the structural materials to increase the insulation values, while new construction can weigh R-values versus ease of construction and cost of those materials. Both new construction and rehabilitated structures have some ability to improve the insulation values of buildings though increasing R-values of actual insulation in walls, ceilings, and floors. Insulation types commonly used above ground include fiberglass batts or rolls, loose fiberglass blown in, or spray foam which may be either open or closed cell. Closed cell is recommended for RAS to best hinder moisture migration. Insulation in the floors is limited to polyurethane closed-cell foam boards below a poured concrete floor.

Selection of insulation is based on cavity spacing, ease of application, and cost. The most common insulation types found in the study were fiberglass batts or rolls in the wall (R-values from 19-30 hr-ft^2-°F/Btu) and loose fiberglass blown into the ceiling/attic area (6-10 inches deep with R-value of 13-22 hr-ft^2-°F/Btu). One operation used 0.5-inches of closed cell foam as a vapor barrier with loose fiberglass, while another used 3-4 inches of closed-cell foam as the principal insulation over an existing warehouse ceiling. Several facilities used 1 inch of foam board insulation under concrete floors, while others had simple concrete or gravel floors with no insulation.

In the example above, the exposure factor for the wall is 1/R or 1/9.2 = 0.109 Btu/hr-ft^2-°F such that the total heat loss through the wall is 0.109 Btu/hr-ft^2-F x 92°F temperature difference x 100 ft^2 of area or 1,000 Btu/hr. One can see that as the R value of the wall is increased, the wall exposure factor decreases. To conserve heat, operators want low exposure factors (and it is convenient to calculate one factor for the entire building). Most buildings consist of more than one flow path as ceilings, windows, and doors have different R values and areas associated with each of them. A building exposure factor can be calculated from the component R-values and areas of various parallel flow paths if the temperature difference is the same for each one. The lower the exposure factor, the more heat is contained inside and supplemental heating cost is reduced.

Figure 4. Condensation on the window of a tilapia production barn. Note the algal growth on the left side of the window.

Of course, the exposure factor for a large building is naturally greater than that for a small building. However, if we divide the exposure factor by the floor area, then we can compare the buildings using exposure per square foot. Here are considerations for reducing the exposure factor per square foot:

1. Minimize sidewall heights. This is a consideration for warehouse applications and new construction.
2. Minimize the total window area. Windows have very low R-values, so minimizing the total window area will reduce the exposure factor.
3. Increase the depth of blown-in insulation.
4. Insulate the walls, especially concrete walls, which have very low R values if they are uninsulated.
5. Increase the thickness of framed walls. For example, use 2x6 instead of 2x4 walls.

Condensation control

Insulation, structural materials, and mechanicals will lose efficiency and longevity if moisture enters into wall and ceiling spaces. Condensation inside walls and above ceilings can severely damage structural members and reduce insulation effectiveness without anyone seeing it because it is hidden. The most effective means to block moisture is a 4-6 mil vapor barrier underneath internal sheathing (on the warm side, not the cold side) and over the insulation. The most common vapor barrier is polyethylene sheeting stapled to the inside of the framing members, although as mentioned, several farms used closed cell foam as both insulation and a vapor barrier.

One site did not install a vapor barrier in the ceiling and the resulting moisture condensed on all surfaces in the attic, including the uninsulated metal roof, and dripped down onto the blown-in insulation reducing its porosity and R-value. Some insulation, such as in warehouses, comes pre-wrapped in a vapor barrier material. However, this does not protect structural components like studs and joists. Vapor barriers, one of the least expensive construction materials, could in the long run save the most money by protecting the structure's integrity.

There are numerous options to cover the vapor barriers on walls and ceilings. Sheathing protects the vapor barrier from tears and punctures. The best materials are waterproof and washable, such as painted sheet metal or fiberglass board with a smooth surface. Some of these materials may have integrated insulation.

While vapor barriers protect from condensation inside walls or ceilings, they do not help to prevent condensation on the inside surfaces of the room, which introduces other problems. There is the potential for mold to form on walls and ceilings where free water has formed due to condensation or splashing. If the surface is porous, mold and potentially harmful bacteria can gain a foothold, leading to human or aquatic animal health concerns. For instance, open cell foam should not be left open to the fish rearing environment due to its porosity. In this study, three sites had painted sheet metal sheathing while two warehouse operations had only a polyethylene vapor barrier over insulation or drywall.

Surface condensation is prevented by sufficiently insulating the wall or ceiling. Condensation is most likely to form on surfaces that are exposed to the outside and have low overall R-values, like windows, doors, and especially bare concrete walls. The amount of insulation needed to prevent condensation in aquaculture facilities is greater than for other agricultural buildings because of high temperatures and humidity.

Figure 5. Patchy condensation on the ceiling of a shrimp production facility. Plastic covers on tanks retain heat and moisture within tank environs.

Floors

Flooring is one of the most overlooked components of an aquaculture building. Several parameters need to be considered for both new construction and rehabilitated buildings. For both types, surface drainage needs to be considered. Sloping floors, which carry excess water away to drains for disposal, are best but may not be possible in existing buildings. Some retrofitting to provide drainage is possible but flat floors may not dry easily.

Floors must be able to carry the load of systems and equipment. Water alone has a load of 5.2 lb per ft^2 per inch of depth, so a tank with six feet of water loads 375 lb per ft^2 on the floor. Additionally, equipment such as forklifts needs sufficient support especially in high traffic areas. Buildings to be rehabilitated usually have flooring in place and may need retrofitting. Other considerations include locations of system plumbing, infrastructure, and insulation.

Some operations save space and improve movement of equipment and personnel by burying plumbing or other systems under the flooring to gain head height and give easy access to operations. For existing buildings, this may not be possible, although channels may be cut in a concrete floor to contain plumbing below normal floor height and then covered with grating. For new construction, any gains from burying plumbing or electrical cables may be offset by their inaccessibility if a concrete floor is poured. Again, to provide access, plumbing may be channelized or concrete can be poured in sections so that pieces may be removed if a problem develops in the future.

Based on our calculations, significant heat loss occurs in aquaculture buildings through uninsulated floors. Floor heat loss becomes less significant for inside building temperatures that approach the ground temperature of 50°F. In fact, the heat loss through the floor is zero if the inside temperature is 50°F. A typical inside temperature of many livestock buildings in winter is 60°F and the temperature difference that causes heat loss is 10°F. Since the calculation is a bit inconvenient and the temperature difference is low, it is often ignored. However, in RAS, the inside temperature is typically 80°F, even in winter, thus the heat loss through a given floor is three times higher because the temperature difference between the floor and the inside air is 30°F, as compared with only 10°F. Livestock buildings with inside temperatures of 80°F or more in the winter are only for small animals and birds. For example, a broiler house is around 80-90°F during the first few days of a chick's life and only under the brooders, whereas RAS temperatures of 80°F are constant throughout the winter and throughout the entire building. The higher indoor temperature also extends the heating season.

The heat lost through the floor can be calculated as the floor area (A) times the temperature difference (°F) divided by the floor's R value (hr-ft^2-°F/Btu) or (A/R)*(Ti-Ts). For example, if a 1,000 ft^2 uninsulated concrete floor has an effective R value of 13.6 hr-ft^2-°F/Btu and assuming 80°F and 50°F for inside and ground temperatures, the heat loss would be 2,206 Btu/hr. Increasing the floor R-value to 18.6 hr-ft^2-°F/Btu with a 1-inch thick blueboard (extruded styrofoam polystyrene) insulation under the concrete would decrease the floor heat loss by 27% to 1,613 Btu/hr.

Since both temperatures are constant, one can calculate the energy savings over a four-month heating season as 2,206 – 1,613 = 593 Btu/hr x 24 hr/day x 30 days/month x 4 months = 1,707,840 Btu = 501 kWh. At $0.10/kWh, the annual amount saved per year would be about $50. Other advantages of the additional insulation include a floor with a warmer surface that is more comfortable for workers and attracts less condensation. Floor insulation is a must if the floor is heated with tubes or coils embedded in the concrete.

Aside from the structure of the building, several systems such as HVAC, electrical service and wiring (including lighting), and water supply are integral to providing an adequate environment for RAS systems. Air blowers, heat exchangers, and other appliances can have an impact on the building environment.

Figure 6. An electric heat pump and bulk storage tank in a mechanical room/ closet. Used for radiant floor heating of a shrimp room.

Heating

The primary concern for most producers, however, is how to heat water efficiently. There are multiple ways to heat the fish's environment, by heating the air in the building first and the water indirectly, or by direct heating of the aquatic system. This is a major decision and of course, the price and availability of the energy source enters into the decision. There is no standard heating scheme for aquaculture operations. Some operations choose to heat the air with either a furnace (already in place) or more likely hanging gas furnaces, which free up floor space for production equipment and systems. Heating the air will hold water temperature consistently but it will take at least one day for 85°F air to heat every one-foot depth of water in tanks from ground water temperature to system temperature; thus, it will require about three days for the air to heat ground water to system temperatures, in a 3-ft deep tank.

There are a number of techniques for transferring heat directly into the system water and thereby heating the building. Generally, water is heated by a boiler or tankless hot water heater. The heated water then transfers that energy to systems through a heat exchanger which may be as simple as coils of tubing such as PEX in one part of the systems or a more formal heat exchanger where pumped water from the systems flows in the opposite direction as the heated water while separated within titanium plates.

The size of heater necessary to heat 100,000 gallons of groundwater at 50°F to a tank temperature of 85°F in three days is about 350,000 Btu/hr or 3500 Btu/hr per 1,000 gallons of tank capacity. If the same 100,000-gallon volume of water has a total exposed surface area of 4,000 ft^2 in a room at 82°F air temperature and 75% relative humidity with a surface air velocity of 100 ft/min, the heat required to maintain the temperature is about 45,200 Btu/hr. Assumptions are: 1) uninsulated tank sidewalls have an R-value of 1.6 hr-ft^2-°F/Btu and overall area of 3,008 ft^2, 2) the insulation value between the bottom of the tanks and soil is 13.6 hr-ft^2-°F/Btu and the ground temperature is 50°F, 3) tank and room air temperatures are 80°F and 82°F, respectively, and 4) the heat required to vaporize the water is split evenly between the water and the air.

Most of the 45,200 Btu/hr of heat capacity is due to the heat lost in the water evaporation process. Specifically, nearly 9,000 Btu/hr is lost through the floor from beneath the tanks, 2,200 Btu/hr is needed to heat up the make-up water, 38,000 Btu/hr is used to evaporate the water, and 3,700 Btu/hr is gained from the air through the sidewalls of the tanks.

How big does the overall heating system need to be? Let's calculate the air heater size for the building in winter assuming an inside temperature of 82°F and an outside design winter temperature of -2°F. A reasonable air volume for this volume of water is 75,000 ft^3 and the ventilation rate at 1.0 air change per hour would be 1,250 ft^3/min (very similar to an Indiana shrimp site we observed in our study). At this flow rate, the heat lost via the ventilation air is 104,400 Btu/hr.

The exposure factor for this building is assumed to be 800 Btu/°F which is only slightly higher than that of the Indiana shrimp building. With this assumption, the heat lost through the building envelope is 67,200 Btu/hr. The total heat capacity required to maintain inside air temperature at 82°F when outside temperature is -2°F is 209,500 Btu/hr, and including the heat needed to maintain water temperature, the overall total heat capacity required is 251,000 Btu/hr. About 30% of this figure is due to evaporation of the water from the tanks. Covering the tanks can therefore reduce the required heat capacity by a maximum of 30% in this building.

Natural gas, if available, is currently the preferred energy source but liquid propane is typically used in rural areas. Fuel oil and even wood could be used. None of the producers in this study used solar energy to heat either water or air, but the authors have visited facilities where solar is used to preheat the air. Like any new technology, adoption will increase as the cost of said technology drops.

Ventilation

Ventilation impacts heat loss, but more importantly helps control the humidity in aquaculture buildings by removing moisture, which in turn reduces the dew point temperature of the air. This is especially important in colder climates. Dew point is the temperature at which water vapor will condense into free water. Any surface that has a temperature at or below the dew point will produce condensation. For example, a soda can from a 40°F refrigerator will easily condense inside an RAS at high humidity (because the dew point temperature of moist 85°F air can be expected to range from 65-80°F). So will any other surface with a temperature less than the dew point temperature.

Dry bulb temperature refers to the air temperature taken with a regular thermometer exposed to the air. Dew point is equal to dry bulb temperature at 100% humidity, which means condensation would occur everywhere. At 90% humidity, the dew point is less than dry bulb temperature but some surfaces (windows, bare concrete walls, walls with with lower than normal insulation) will still be cold enough to condense water from the air. As humidity is lowered by ventilation air exchange or by covering tanks to reduce the moisture load, surface condensation will be greatly minimized.

There is a trade-off between heat loss from ventilation and humid conditions in the building that may lead to condensation, mold, poor air quality, and long term degradation of the building structure. The recommended ventilation rate for RAS is 1-2 air changes per hour (ach). Calculate total volume in the room and divide by 60 to determine the total cubic feet per minute (cfm) needed for one air change. For example, the volume of a 10 ft high, 60 ft wide, and 100 ft long building is 60,000 ft^3. The ventilation rate for one air change per house is 60,000 ft^3 / 60 min = 1,000 cfm. Thus the recommended ventilation rate for this RAF would be 1,000-2,000 cfm.

Only two of the five sites we evaluated had ventilation airflow rates that were above 1 ach (1.16 and 3.03 ach), which were achieved with airflow rates of 1,172 and 4,076 cfm, respectively. The others were 0.16, 0.30, and 0.68 ach, which were attained with ventilation capacities of 181, 208, and 3015 cfm, respectively. The facility with 0.16 ach supplemented the small heat exchanger airflow rate with natural ventilation by opening doors and windows. In this case, the heat exchanger needed to be about six times larger (1,100 cfm) to reach the recommended 1.0 ach. The facility with 0.30 ach used expensive desiccation to remove moisture, but it is more economical to use ventilation instead of desiccation to remove the moisture. The building with 0.69 ach had very high headspaces because it was built into an existing warehouse and the fresh air exchange was hindered by a poorly maintained ventilation system.

Heat exchangers

One means of ventilating while reducing heat loss is to use a heat exchanger or thermal wheel. Warm moist air is vented out through a mechanical air movement device that collects the heat and transfers it to cooler incoming air. The unit should be sized for ventilating the building at 1 ach, which is the minimum ventilation rate for condensation control. Once installed, the heat exchanger will save on energy throughout the heating season.

Most of the farms visited in our study had condensation issues during winter visits due to poor ventilation. The ones that did not have issues either had high ventilation rates (accidental) or used large dehumidifiers. One operation was installing a heat exchanger, which was not yet functional during the study.

Electrical

All the operations studied had no electrical problems. Electrical panels and controls were mounted well away from any water or exposure to highly humid air, and in some cases were housed in a separate room. Wiring was either internal to the wall, or mounted in conduit and electric outlets that had covers. Outlets or circuits should have ground fault interrupters to reduce the risk of electrical shock. Lighting can vary greatly from standard fluorescent bulbs to newer LED technology. In all cases, they should be covered to decrease the risk of water damage and shorting.

Water pumps and air blowers

Water supply and discharge are important considerations when deciding on a building. In rural areas, supply is generally from wells so quality (per species) and quantity (per exchange rate) are issues. In more municipal areas, wells might be an option, but if using municipal water, treatment to remove chlorine-based sanitizers will be necessary. Likewise, in rural areas, discharge usually consists of settling basins or lagoons and the wastes are land applied when necessary. Sizing is important so that applications are not done too frequently. Land for receiving application of this waste should also be planned out. If in a municipality, the only discharge option may be through the municipal sewer, which while convenient, might be costly.

Several common aquaculture accessories generate heat and affect the humidity of aquaculture buildings. Water pumps and air blowers generate heat from the friction of moving parts, which can be transferred into the water. Water pumps do not add a noticeable amount of heat, but regenerative air blowers can generate enough heat to discolor or even melt PVC pipe if not installed correctly. Neither, however, should be considered as a significant contributor to the necessary heating plan of a building. Nonetheless, air blowers can have a significant effect on the amount of water vapor inside a building.

Outside fresh air will have a normal profile mixture of oxygen (approximately 21%), carbon dioxide (about 400 ppm), and water vapor (relatively dry). With all the biological processes going on in the systems, oxygen is consumed and carbon dioxide is produced. A typical total blower capacity is about 50 cfm. Air blowers can easily be plumbed to draw from relatively dry outside air or recirculate warm moist air with elevated carbon dioxide levels within the building. In either case, blower air is percolated up through the water column in the tanks as saturated air bubbles that are then released into the atmosphere at 100% humidity.

If blowers draw air from outside rather than inside air, then:

1. The blowers will remove more water from the tanks because each cubic foot of air is able to remove more water if it enters the water dry (outside air) as compared with starting out moist (inside air). This means more makeup water will be required, which will need to be heated as well. It also means more room ventilation air exchange is needed to remove the added moisture load.
2. The blowers will run a bit cooler, lowering heat input into the tanks, but this effect should be negligible.
3. Depending on how well the room is ventilated, more carbon dioxide, which is quite soluble, will be removed from the tank. The blower inlet air, if recirculated from room air, will have less than 1,000 ppm of carbon dioxide if well ventilated and greater than 1,000 ppm if poorly ventilated, whereas outside air has about 400 ppm of carbon dioxide. Excessive levels of carbon dioxide were not observed in this study, except in conditions of no ventilation.
4. The blowers may last longer if they are not exposed to moist air from inside the building.
5. Because fresh air means better carbon dioxide removal, it is recommended that blowers draw air from outside to bring in fresh air.

Summary

Proper construction or rehabilitation can give the owner a functional building that meets rearing criteria, but it will only last a long time with proper management. Obviously, heating and ventilation are the most important building management decisions. Experience through the first year will help the operator understand the balance between outside and inside environmental conditions and the cost of heating versus ventilation to keep humidity at bay. Automation may help with this. Temperature control of the room should be automatic based on temperature sensors in the room. Relative humidity sensors are often unreliable and don’t last long. Observe condensation and increase minimum ventilation rate until condensation is controlled. If condensation is controlled, carbon dioxide and other pollutants will be controlled as well.

Reference

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