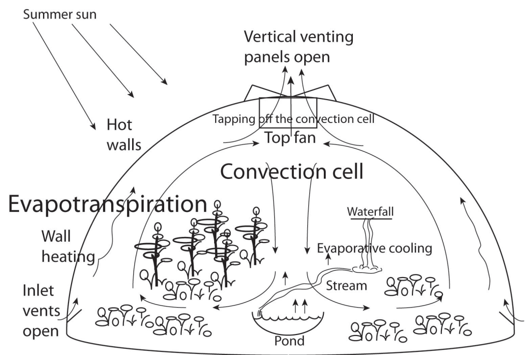
HVAC in the Biodome

The following description weaves together the evapotranspiration cooling system, the passive solar design heat storage elements, solar geometry and its relation to plant placement for seasonal shading of the passive solar elements, dome design contributions, code requirements, and public health considerations. While avoiding extreme complexity, to provide an understanding of the details basic terminology like thermal gradients and convection cells will be needed.

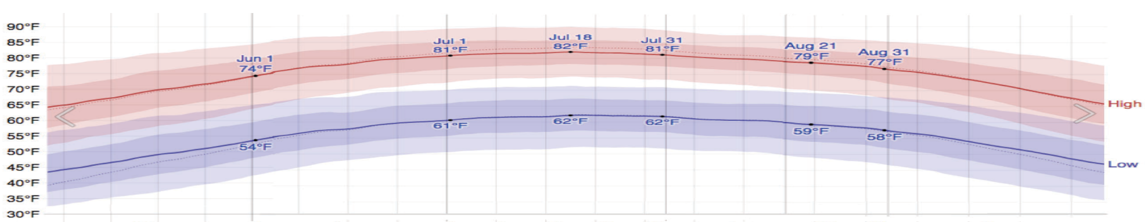
In the spring and summer greenhouses capture too much heat and sunlight, and cooling is a necessity. The **evapotranspiration cooling system** will utilize the thermal absorption from the 11,000ft^2 of tropical plants evaporating over a half million gallons of water as part of their life processes, providing up to 4.6 billion BTUs of cooling capacity.



Evapotranspiration cooling by plants & pond

In the Biodome, vents at the top of the dome set up a chimney-like draft, tapping off the convection cell created by rising air heated at the sunlit walls. Outward airflow is enhanced by a quiet exhaust fan at the top. Cool air is draw in through a ring of inlet vents at the base of the dome. Other botanical gardens are 8^o to 10^o F below outdoor temperatures from their combined evaporative cooling.

Warm season temperatures in East Lansing peak in the 90s (see below). While 10^{o}F below ambient peak temperatures is not in the 72^o to 74^o air conditioning optimal comfort range, the summer average high of 83^o would lower into this range. Coming into a building from outside, a 10^o drop would be a comfortable improvement. Augmenting the evapotranspiration cooling and plant shading will be shading from the building-integrated transparent solar panels overhead.

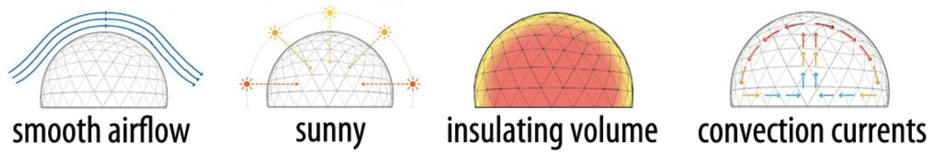


East Lansing temperatures, line - average, dark shading 25-75%, lighter 10-90th percentile

In 2019, the DOE benchmarked the average energy consumed by cooling equipment of commercial buildings at approximately 3 kWh/ft^2. For the 17,671ft^2 Biodome that would be 53,013 kWh per year of energy use, not considering the actual volume of the internal space. Subtracting the electrical power usage for the top vent fan, the reduction of electricity consumption due to the evapotranspiration cooling is over 52,000 kWh/yr.

Wintertime heating and fresh air requirements

The advantages of the Biodome are lessened heat losses because the external laminar wind flow over the curved surface lowers heat exchange due to the absence of turbulence from edge vortices.



On the other hand the transparency of the structure leads to more radiative losses, though fortunately glass retains infared light, which it reflects. The need to transmit sunlight requires walls of insulated glass that are still not as insulating as a normal thick wall.

The volume inside the dome helps retain heat, as air itself is a good insulator. This is until convection currents caused by cooling at the walls establish an internal convection cell with heat transfer and losses by bulk transport eliminating the volume insulation effect. So working to prevent these currents within the dome would enhance the heat retention characteristics.

The heating system and building code air turnover requirements add more complexity. The basic heating system is a finned-pipe steam heat register encircling the inside base-wall upon which the dome sits. This ironically puts the facility's heat input adjacent to its prime loss area and sets up a high gradient to drive the heat loss. Even so, this is not an uncommon arrangement because it has advantages for better heating regulation, keeping the equipment in a steady on-off cycle while achieving even heat distribution without wildly oscillating temperature spikes or hot and cold spots. During the winter two thirds of the heat needs to be supplied from external sources.

Heating around the rim of the dome does oppose the descending cool air generated along the dome walls and counteracts the driving forces of the natural convection cell. In the winter with the vents closed, reversing the fan to blow downward pushes the day's solar heat capture down from collecting in the top of the dome into the garden. Both of these effects oppose the wintertime convection cell direction, which is downward along the cool walls, but they might combine to produce a similar summertime pattern as the up-the-hot-walls cycle and still create a heat loss enhancing bulk flow. It is hard to have a still insulating air condition taking advantage of the dome's size.

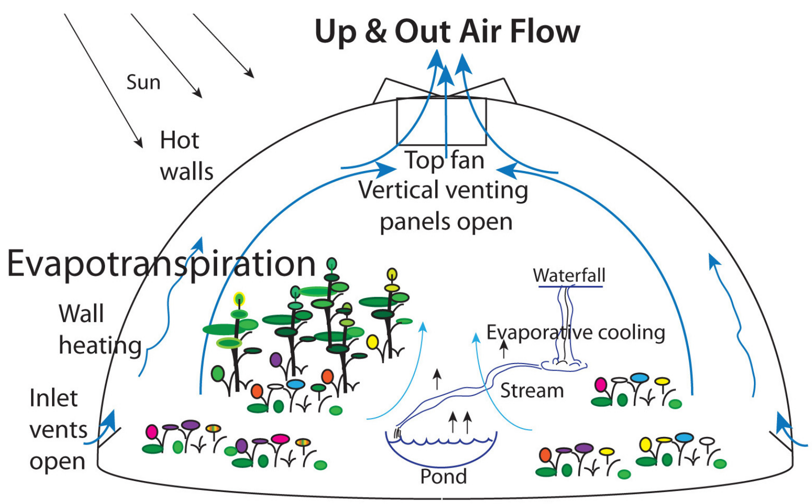
Venting at the top of the dome to the outside with air from base of the dome inlets produces the air changes per hour (ACH) to meet standards in the spring, summer, and fall. National standards require 0.35 ACH, though 3 to 4 ACH is considered optimal. During the winter this air turnover requirement is satisfied by fresh air injection from air handling equipment located in the mechanical room of the North Entry Building. Air withdrawn from the dome is replaced with warmed and humidified outside air conveyed to the dome through conduits above and below the connecting hallway between the buildings.

The dome has an internal volume of 883,572 cubic feet. 8’ x 4’ across air conduits delivering and retrieving air from the building, moving air at 1000 ft/minute or 32,000 cuft/min. into the dome will achieve 2.17 ACH. The air speed is 11mph, which is considered a gentle breeze. Halving or quartering this input may be acceptable, and lulls the breeze even more.

Along the main conduits running under the internal buildings floors small vents provide air exchange into the room spaces. A vent of a square foot would provide the community room with excess of 4 ACH. Smaller 6” square vents would provide like turnover in the conference room, storerooms, and office. The workroom spur shaft and vent would be intermediate in size for proper ACH.

Public Health, Gathering Places and COVID

The Biodome is a nature oasis with live growth, waterfalls and the physical space of the outdoors. Beyond the visible it has an air flow pattern that improves on the outdoors’ dilution and disease transmission breaking characteristics by the ‘Up and Out Air Flow’ shown below.



During the spring, summer, and fall, when the dome is capturing ample solar heat, cooling is supplied by evaporation from plants and water features. This heat absorbing capacity is maintained by venting the water vapor, keeping the humidity low and comfortable, and facilitating continued evaporation. The airflow pattern is better than the outdoors for social distancing because it draws airborne particles away from visitors, up over their heads, and out at the peak of the dome.

In the winter, when the Biodome needs added heating, the same Up and Out Air Flow pattern can be continued if the air at the top of the dome is removed for air turnover requirements instead of at ground level, as previously designed. This sacrifices some heating efficiency because solar heat capture naturally accumulating at the top of the dome is not blown down into the garden but extracted to the external air handler/heating system. This illustrates the Biodome is a versatile, valuable, social gathering hub even in the uncertain times.

Passive Solar Design Features

The passive solar design features are two main thermal mass heat absorbers in the southern half of the dome's interior layout positioned to intercept the low angle winter sun and store heat for overnight release.

The cliff face angled toward the south will intercept 90% of the day's incident sunlight during the winter. As a passive solar thermal mass over a foot thick, it will absorb heat during the day and re-radiate into the community room behind. The stage platform in front of the cliff is both a reflector of low angle winter sun onto the cliff face and an additional absorbent storage mass. The dark shade of brownstone used for the cliff increase the absorbing efficiency.

The large southern pond serves a heat absorbing/ storing purpose, and the dark bottom of the pond increases heat capture, while the large volume of water provides a large thermal storage capacity. The water is moved through the full length of the interior and the waterfalls enhance the heat exchange

In the summer these same features continue to help with the thermal regulation of the Biodome interior. The pond, stream and waterfalls now become evaporative coolers, while the cliff's heat accumulation is limited by shading foliage. At lower winter sun angles, the sun shines directly through the palm tree trunks behind the seating onto the absorbent stone, but in the summer higher sun angles cause the overhead foliage to shade the stone and minimize heat gain.

Coupling of the solar panel's shading, foliage shading seasonally attenuating passive solar thermal mass absorption, and the evapotranspiration cooling will make this facility a living homeostatic environment for visitors to experience.