2012 Energy Conservation and storage by Dr David Mears, Rutgers University

1. This class focuses on some key aspects of energy conservation and several examples of the role thermal energy storage can play in greenhouse environmental control. It is important in considering the role of various energy management technologies the impact on the ability of the grower to maintain, or even better, improve some aspects of environmental control. A case can be made that some energy management technologies have a bigger impact on crop improvement by giving the grower additional control capability than the impact of the energy cost savings. Also energy conservation and management systems that reduce the use of fossil fuel do contribute to solving the global warming problem. These notes are based heavily on my own experiences and the R&D program at Rutgers in greenhouse engineering so is very much a first person presentation.

2. My first greenhouse experience turned out to be very much related to the major energy input for the industry. A nearby greenhouse was heated by coal fired steam boilers in a basement. Saturdays it was my job to haul the ashes up from the basement and clean the boiler tubes of the coal soot as shown here. I had no idea that in the future a major part of my career would be trying to avoid as much use of coal and other fossil fuels for greenhouses as possible.

3. My college roommate and I helped our structures professor build this air supported bubble. Several years later Bill Roberts got the idea to use the air pressure between two layers of plastic film for commercial greenhouse construction. A few years after this development there was substantial interest in air supported greenhouses and several were constructed and operated at the scale on the order of an acre or large portion thereof.

4. The first practical air inflated double poly greenhouse has been made a landmark. I did have the satisfaction of working with Bill on the mathematical analysis of the film stress to determine good design practices and later the structural design principles for larger, gutter connected structures. Starting in the late 1960's much of our effort turned to energy efficiency and environmental control issues. The full story of the development and impact of this technique can be found from the link on the webpage home or directly from: http://aesop.rutgers.edu/~horteng/ASAE%20Landmark.htm
Note there are a number of powerpoint presentations available from that page.

5. The very first experiment at Rutgers was to measure the difference in heat requirement obtained by moving all the heat source under a black shade cloth system and the very encouraging results led to a search for better materials and systems to obtain energy conservation Our early research on curtain insulation systems depended on home made systems of moving the curtains and whatever materials we could find, many of which did not work very well. Later on many companies have developed advanced systems and curtain materials with excellent properties for night insulation and daytime shading in excessively hot conditions. The 1981 paper on curtain systems in the presentations section:
http://aesop.rutgers.edu/~horteng/ppt/papers/MovableCurtain.pdf
has detailed information on the thermal properties of the materials tested to that time. Today there are a number of materials available commercially for complete systems and some properties information on these is available on the suppliers websites etc. Many of these materials provide partial shade for reducing thermal stress in daytime as well as heat conservation at night. Also it should be noted that commercial acceptance of this technology moved into the industry more rapidly as the ability of the systems to improve micro climate control was recognized.

6. Although the air space in double poly structures saves energy, the direct radiation loss through pure polyethylene is much greater than glass and some other plastics. Research on curtain systems documented the portion of the heat loss from double poly covered greenhouses that was direct radiation to the external environment For some time we discussed the potential benefit of introducing an infra red heat absorption component with film manufacturers. Research on that concept with full support from the manufacturer was started on our campus, resulting in the commercial introduction of IR film which does provide significant energy savings. The link from the presentations page for the results of that research is: http://aesop.rutgers.edu/~horteng/ppt/papers/Cloud9.pdf
Note that one can draw an analogy between a greenhouse glazing and the atmosphere which is the 'glazing' between the planet surface and outer space. Recognizing that introducing an IR absorber into IR transparent film should have a similar effect to introducing more water vapor and/or carbon dioxide and/or methane, which are all IR absorbers, into relatively IR transparent dry air is it any easier to understand the 'global warming' discussion?

7. An important aspect of this IR film project for us was that with full industrial support we were able to improve our instrumentation systems greatly. This enabled us to determine the details of the heat transfer from the greenhouse as impacted by external weather conditions as well as the film properties and develop the relationships presented in the paper.

8. The major energy savings factors for commercial greenhouses are illustrated, first by comparing single versus large multi span glass structures where the savings is due to much reduced wall area. For multi span structures the savings of plain double poly relative to glass is due primarily to the trapped air space between the layers. Heat curtains add another dead air space and reduce direct radiation. The use of an infra red absorption additive to the poly also reduces radiation and the greatest energy savings are achieved by the use of all these methods. Root zone heating may result in additional savings due to more uniform temperatures and possibly reduced air temperatures for some crops.

9. Our horticultural colleague was concerned about cold soil temperatures for tomatoes growing in troughs of media on the ground. We designed a system for ducting the warm air from the heating system under the walkways thereby warming the root zone which did help the crop.

10. We had long been interested in the concept of utilizing the warm water from power plant cooling systems for greenhouse heating and were thinking of ways to deliver heat from the warm, not very hot, water to the greenhouse and realized large areas for heat transfer would be required as there would be a low deltaT between the warm water and the greenhouse environment. Ironically this paper did not gain us any support for a waste heat project at the time but a discussion of the difficulties of using solar energy for commercial greenhouse heating did lead to our being approached by USDA to participate in their research program on that subject. This paper is listed on the presentations page and can be found at the following link: http://aesop.rutgers.edu/~horteng/ppt/papers/HeatingConcepts.pdf

11. In addition to the research on energy conservation there was also research on a variety of ways to provide root zone heating through floor heating systems. The heat transfer parameters and descriptions for some of these concepts are in the first paper on floor heating in the presentations section:
http://aesop.rutgers.edu/~horteng/ppt/papers/FloorHeating3.pdf
This leads to an obvious choice to use the greenhouse floor as the primary storage for the heat collected in a solar system as it can also serve as a large area, low deltaT heat transfer system for the night.

12. Even before the results of the first year of research being conducted at eleven land grant universities was reported, the Department of Energy issued an RFP for commercial demonstration projects of at least 5,000 square feet. A large, half hectare, solar greenhouse demonstration project featured the energy conservation features already covered and included a floor storage system for the water warmed by the low cost solar collectors. Most importantly, it was an early demonstration of the positive effect of the energy saving curtains and warm floor heating system on plant production and quality as well as the energy savings. The project attracted many visitors and I believe that the reported benefit to the environmental control of the plants due to the curtain systems and the floor heating feature contributed significantly to the rapid commercialization of both of these systems. There are several papers on the R&D on solar systems on the presentations page and a comprehensive paper on the demonstration project is at the direct link:
http://aesop.rutgers.edu/~horteng/ppt/papers/SolarHeatingKubePakReport.pdf

13. The spaces between the gravel laid out on a plastic liner provide very large thermal storage and the floor surface becomes the primary heat exchange surface. It is only warm and does not overheat the plants and working in this greenhouse one would easily get the idea that similar warm floors would be a good feature in a residence or office as well. The very large thermal storage allows for substantial energy inputs and outputs with small changes in the temperature of the storage.

14. The low cost plastic film collectors were designed with very similar technology as double poly greenhouses. These collectors are very efficient warming water to temperatures in the range of 30 to 35 C which is quite suitable for a warm floor in a greenhouse but their efficiency would diminish rapidly if trying to collect energy at much higher temperatures.

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16. Before we were able to convince an electric utility to become engaged in waste heat applications we were involved with one on the potential to utilize landfill gas. We looked into cogeneration with a small engine designed to operate on natural gas or landfill gas. The research project results and some theoretical simulation studies based on those results are presented in papers on the presentations page. The link to the paper on the research program that utilized flooded floor storage similar to that used in the solar programs is: http://aesop.rutgers.edu/~horteng/ppt/papers/CogenforHeating.pdf

17. More recently we looked specifically into the impact of energy storage capacities on the effectiveness several basic energy systems: cogeneration, fuel cell and several heat pump systems. The paper on these systems is also on the presentations page and the direct link is:
http://aesop.rutgers.edu/~horteng/ppt/papers/HeatPumpStorage.pdf
In all of these systems a major advantage of heat storage is that the size of the primary heat delivery system can be substantially reduced from the requirement to meet the peak heat requirement. This graph shows the increase, relative to what would be provided without storage, in energy utilization in the greenhouse for different size co generators with increasing storage. A very large co generator will get less relative benefit from storage as it can meet more of the load directly.

18. Lessons learned from the solar project, included the benefits to the crop management as well as energy conservation aspects of the curtain and floor systems and documented the performance of the

floor heating concept with warm rather than hot water. Mathematical modeling with real data on the temperatures of the water from the power plant condensers indicated the importance of energy conservation to reduce peak heating demand. It also showed that significant savings in the investment in overhead heat exchangers using the warm water could be obtained by using the fossil fuel fired backup system, (needed in case of interruption in warm water supply), as a touch up system to provide peak heating requirements at the coldest times. The first four papers under 'waste heat utilization' in the presentations section describe the research behind the design, the design process and two reports on the performance of the first 3 acre block. The large thermal storage in the floor evens out variability in the temperature of the incoming water from the power plant. It also provides a significant safety factor if the backup system is not available and there is a shutdown at the power plant.

19. In later years there were a number of greenhouse blocks added to the complex. Different floor systems were utilized including some areas without the flooded floor storage and some with a concrete ebb and flood floor system. The six acre block just north of the original 3 acre block was built for a company producing greenhouse tomatoes and later sold back to the operator of the first block. The entire complex west of the road has changed ownership several times. After significant structural damage to some of the greenhouses due to a heavy snow storm some of the heating systems were re-designed as described in the last paper in the waste heat set:
http://aesop.rutgers.edu/~horteng/ppt/papers/RedesignWasteHeat.pdf

20. In recent years we have been using models to help design potential research and development projects. A 2007 paper: http://aesop.rutgers.edu/~horteng/ppt/papers/HeatPumpStorage.pdf discussed designs including co generation, fuel cells and heat pumps. These results show the contribution by months for a system where the hourly capacity of the heat pump to move energy is quite small relative to peak heating or cooling requirements. When cooling is needed the heat pump uses the greenhouse heat exchanger as a source to pump heat into storage and uses a geothermal well as a source at other times. Tables in the paper show the effects of different combinations of capacity for the three elements, heat pump, storage and heat exchanger. Storage substantially increases the potential annual contribution of relatively small size heat pump units.

21. In Taiwan there is a unique opportunity to use a heat pump system with warm and cool storages in the orchid industry. Cooler day and night temperatures are needed to induce flower initiation, (spiking), than can be achieved with ventilation so mechanical cooling is needed. The heat rejected by the cooling heat pump can be stored in the warm tank to provide the relatively small amount of heat required in that climate in the breeding greenhouses that are kept at higher temperatures than the flowering ones. This project is by Dr. Wei Fang, National Taiwan University.

22. Building on the modeling work with cogeneration, fuel cells and heat pumps we have been modeling a number of potential heat pump systems for several greenhouse types in several different locations in Japan. The most common type heat pump system in use there is the air source-air output type where both the heat pump condenser and evaporator are refrigerant to air heat exchangers. For a geothermal heat pump system one of these heat exchangers will be refrigerant to air in the greenhouse and the other refrigerant to water tied to the geothermal source. The third option is with both heat exchangers on the heat pump the refrigerant to water type and in this case a separate heat exchanger will be needed between the water storage and greenhouse environment if there is a storage. The modeling studies have been done with the operating characteristics of representative commercial equipment and the results are in press in a Japanese journal.

23. Current research with our colleagues in Japan is looking into the use of a water-water heat pump system with warm and cool storages and a geothermal type source that can be used for both heating and cooling. This contrasts with a geothermal system with storage used for either heating or cooling by depending first on the two storages. During periods when day cooling and night heating are both needed a relatively small heat pump can run continuously pumping heat from the cool to the warm tank. In warmer weather the warm tank will be replaced by the well to dump heat and in cooler weather the well will be the source for pumping to the warm tank.

24. Part of our horticultural engineering curriculum was a capstone senior design course, usually team efforts. One group investigated the concept of using a biogas digester to provide fuel for a co generation system to see how the inputs and outputs of the various components would match up. The results were encouraging if the digester were in the greenhouse and the dimensions were correct to match the heat transfer rates from engine to digester to greenhouse to keep both the digester and greenhouse temperatures in reasonable ranges. The bio gas needs to be cleaned up before use in the engine and the CO_2 in the biogas and from the engine can be cleaned up to supplement growth in the greenhouse. Working out all the details on such a system should be an excellent academic exercise at the very least.

25. There is great and increasing interest in a variety of ideas to bring intensive agricultural operations into urban areas. Some are operational and many concept ideas are presented on the internet and elsewhere. In March 2010 there was a meeting in Tokyo discussing agriculture in the metropolitan area including discussion of projects involving the green roof concept, open plantings on roof tops which can have positive impacts on the urban ‘heat island’ problem in summer heat.

26. We have been working with our Japanese colleagues on the concept of greenhouse spaces attached to residences or other occupied buildings. The model above is a cross section of a long row of apartments with greenhouse space along the south wall. For computer modeling we are just doing calculations for a 1 meter width in the middle of the unit so the final results would be multiplied by the total width of the structure. The model is based for the most part on the preceding sunroom studies and uses a weather data base for Tokyo.

27. The potential contribution of the heat needs for both units for different heat exchange and storage capacities. For the greenhouse any of the heat exchangers of size 20 or above combined with significant storage capacity almost eliminates the need for backup heat. For the residence which is being kept at a warmer temperature there are increasing benefits with increasing the capacity of the heat exchangers and increasing the size of the storage. Even more combinations of heat exchange and storage capacity for different sizes of residence and greenhouse can be studied and cost considerations will be a factor in making design decisions.

28. Many of the conferences I spoke at in the late 1970’s featured other speakers explaining the virtues of greenhouses attached to residences which they anticipated would provide all the energy and much of food for the house. Unfortunately none had reliable data and many concepts were clearly not feasible. Impressed with the success of the preceding commercial project and needing to do a renovation on our own house we decided to take on this type of project using the best ideas we had from the research we had done and to actually document the results. Note that years later our Japanese colleagues who had stayed with us during visits to Rutgers were inspired to start some research on this concept of which the modeling study in the preceding slide is part.

29. The original farm house was constructed in the 1860's on a foundation dating to the 1790's and was in much worse shape when we bought it than shown here. It was essentially unpainted, had no insulation and many of the siding boards were broken. We needed more space, particularly for our house and garden plants that filled all the window spaces. The 25 year progress report is at: http://www.livescience.com/environment/060421_green_house.html and a report on the design, construction and performance is at: http://aesop.rutgers.edu/~horteng/ppt/papers/SolarHeatedHome.pdf

30. The design concept included an addition on the back of the house with the flooded floor system under a tile floor and an attached greenhouse also with the flooded floor storage caped with pretty pavers. The solar collector originally heated the floors but later was modified to heat the domestic hot water in summer. The back up system is a wood stove with an internal water coil that can heat the water in both floors. Having a 2 hectare woodlot as part of the property means there is a sustainable wood supply without need to cut any living trees, just harvesting natural dead wood.

31. The swimming pool liner encloses the water which can be circulated through the woodstove for backup heat.

32. This shows some of the features of the old house that certainly needed improvement.

33. We did much of the work ourselves.

34. Brother and sister helped. Note how the greenhouse addition overlaps the old house and the addition and warm air can enter the old house through the window.

35. The vertical blue foam insulation helps insulate to the cold outside but the insulation on the bottom is mainly to cushion the plastic liner to avoid getting holes in the liner while carefully filling it with the stone from the pile behind in the picture.

36. The liner goes over the insulation cushion.

37. Construction of the greenhouse floor is essentially the same as commercial greenhouses.

38. The floor storage for the residence is also very similar to commercial greenhouse examples but will have a concrete slab on top finished with pretty quarry tile.

39. Our daughter helped install the piping for the backup wood stove. She is currently the recycling coordinator for Anchorage, Alaska and mother of two of our grandsons.

40. A difference with greenhouse floors is the top layer of plastic sealing the water in with the gravel. There is one opening to an inspection port which is not shown yet where the circulation pump is installed.

41. The greenhouse is single glass as the double glass options at that time were not practical. If rebuilding today it is likely we would use double pane glass. The solar collector is an extruded EPDM material with fine tubes on close spacing glazed with greenhouse grade Fiberglas.

42. The renovated house with the addition on the west and the greenhouse in summer.

43. The greenhouse floor is pavers over the gravel holding the water. The main use of this space is for pleasant living and for ornamental plants.

44. These two pictures show the movable night insulation curtain system which became the daily chore for the children to open and close at the appropriate time. Our daughter is exaggerating the difficulty of pulling it and such systems are often mechanized. Note the snow on the outside of the knee wall.

45. It is very nice to have a view of the snow through the glazing of the greenhouse filled with flowering plants on a cold winter day. The data sensor for some temperatures being recorded for the research aspect of the project is on the table near the stove.

46. The difference between the inlet and outlet temperatures of the water flowing through the stove heat exchanger indicate the energy being transferred to either the greenhouse or residence floor storage. The temperatures maintained throughout this coldest night in the greenhouse and the living room were above the setting on the thermostat that would activate the pre-existing oil heating system that was the final backup. That was never needed for space heating purposes during the 25 years we occupied the house but it was used some for the domestic hot water back up.

47. The data from this period demonstrates the advantage of a large capacity thermal storage as the stove could be operated for some time heating the home and adding to storage but then in less than extreme cold weather could be left to go out while the system 'coasted' on the heat stored in the floors.

48. A cold day in winter so note the snow shovel by the door and the wheelbarrow with some wood for the stove.

49. Assignments needed?