From Forest Nursery Notes, Winter 2009

9. The real costs and savings of alternative energy and conservation.
Chambers, J. International Plant Propagators' Society, combined proceedings 2007, 57:337-348. 2008.

The Real Costs and Savings of Alternative Energy and Conservation©

Jeffrey Chambers
Geomatrix, 420 Weber Street North, Unit G, Waterloo, Ontario N2L 4E7 Canada
Email: jchambers@geomatrix.com

In order to develop a better real-world understanding of the true costs and potential savings of different energy conservation technologies, a detailed study of multiple commercial greenhouse facilities was performed. To do this, energy audits were performed at 22 greenhouse facilities in the Niagara and Leamington Areas (Canada) between mid-March and mid-May 2006. These facilities consisted of:

- Six tomato growers.
- Two pepper growers.
- Five potted plants.
- Two cut flowers.
- Three bedding plants.
- Four bedding and potted flowers.

A comprehensive energy auditing program was developed based on our experiences with these audited facilities and others. The auditing program is set-up to accommodate four different levels of participation (with different cost commitments). The figure below (Fig. 1) illustrates the different levels of participation.

Level 1. This is a web-based self-performed benchmarking study that allows multiple users from a wide area to benchmark themselves against other similar facilities based on a limited number of parameters. This program level gives good overall information to benchmark your operations versus peers at a very low cost. Sign up at the Ag Energy Cooperative. Call 519-763-3026 or email Lynda Twomey at <ltwomey@agenergy.ca>.

Level 2. This is a basic energy audit that will provide more detailed operating data and technology summaries for comparison purposes. This level of participation will allow a greater level of "drilled down" in the benchmarking. It gives excellent information for comparison of the actual energy usage impact of installed technologies.

Level 3. The Level 3 participants receive the basic energy audit plus an energy balance model of the greenhouse. The data collected and the energy balance model allows participants to analyze each zone in the greenhouse to compare the cumulative and incremental effect of technologies.

Level 4. This is the ultimate level of participation. It involves installation of energy flow monitoring equipment that will provide a greater level of accuracy and detail in the model, plus real-time tracking of the actual energy entering each zone in the greenhouse, and real-time assessment of the actual effect of each new or existing technology in each zone and what weather/operating conditions make them cost effective.

The 22 demonstration greenhouse facilities participated at the Level 3 and Level 4 audits. Intensive Level 4 audits were completed on four of the facilities and simpler Level 3 audits were performed at the remaining 18 facilities. The greenhouse

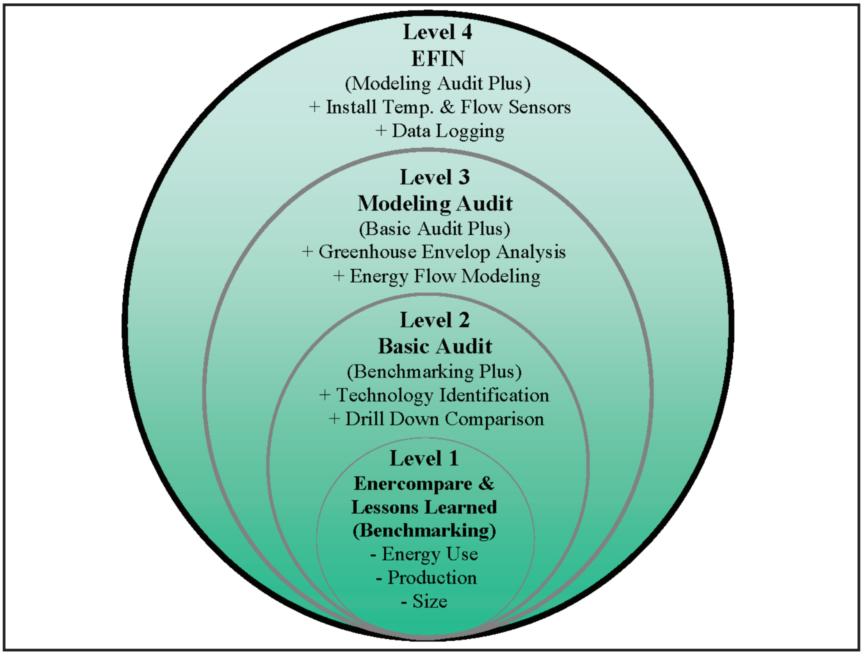

Figure 1. Illustration of the different levels of participation.

energy audits performed on these 22 facilities showed that the average energy used by the facilities was:

- 20.5 kWhr/m^2/year of electricity
- 1.6 GJ/m^2/year of heating fuel (43 m^3/m^2/year of natural gas, or 38 L/m^2/year of oil, or 0.12 tonnes/m^2/year of biomass)

Using the benchmarking data we are able to drill down and make more specific energy usage comparisons based on crop type, geographical location, greenhouse configuration, greenhouse age, and dozens of other criteria.

DETERMINING THE REAL COSTS AND SAVINGS

It is no surprise that the identified range of potential energy savings is quite large. This is due to the fact that the actual savings to be realized by a given facility depends on the physical configuration of the facility, their production practices, and the number and types of other energy reduction technologies already employed by the facility. It is this very uncertainty that plagues and confuses most, if not all, growers. This program was specifically designed to allow a multifaceted and third party assessment of the potential costs savings of energy conservation equipment.

The first and most basic way to assess the effectiveness is via basic benchmarking between facilities. Once the database has enough facilities in it, it will be quite simple to compare facilities which are similar except for one or two energy reduction technologies. This will be a simple "grass-roots" or grower-based technology validation method.

The second way is to perform more detailed energy audits coupled with the dynamic energy balance model. This will allow real-time theoretical assessment of the impacts of specific technologies under varying operating conditions within a given greenhouse or within different geographical areas.

The third way is to perform energy flow analysis within greenhouses that have multiple technologies employed in different zones. This will provide actual real-time energy consumptions by zone, which is a very defensible and reliable basis of assessment.

The forth and final way is via the follow-up technology validation being sponsored by Ag Energy Co-op. This is a follow-on program to the initial audit program, where new cutting-edge technologies are being deployed in the facilities previously audited providing third party validation of the cost and the benefit of these new technologies. This will be an ongoing program, hopefully, for a number of years.

DYNAMIC ENERGY BALANCE MODEL BASICS

Generally speaking, energy that enters a facility leaves the facility (i.e., what goes in comes out). Using this principal it is theoretically possible to develop an energy balance on a facility by monitoring and measuring all of the energy inputs into and out of the given facility. In a greenhouse system, the energy elements include the following:

- Electricity.
- Gas/oil.
- Sunlight.
- Ambient heat from the surrounding environment (depending on temperatures these can be a heat energy contribution or heat energy loss).

While such an approach is theoretically possible, it can be difficult to accomplish in practice. Developing energy balances involves measuring the inputs or outputs from every potential energy source and sink. The level of detail required for a precise energy balance requires considerable expenditure of time and effort. It is therefore useful to conduct general energy audits designed to provide an initial identification of potential energy efficiency.

In such audits, the focus is on identification of sources of energy loss, since identifying these losses provides opportunities to reduce them. Reducing energy losses results in less energy being input into the system, leading to cost savings. To gain as accurate a picture of the energy distribution as possible, two energy balances were calculated.

The first steady-state balance was based upon the results gathered during a site audit. The results from these audits provide a snapshot of energy distribution at the time of the audit. These snapshots are designed to provide a rough estimate of energy distribution and are not intended as definitive balances, which are simply not possible within the short audit period.

Since energy losses are a great concern in greenhouses and provide the greatest potential for cost savings, a second energy analysis was conducted to provide greater insight into these losses. This secondary analysis was based upon data received from individual grower's climate control systems and the Energy Flow Integration Network (EFIN).

The dynamic model then uses the collected data to calculate the conductive, convective, radiative, and climate control system energy gains/losses. This in turn allows for simulation of the impact of different energy conservation technologies.

SEMI-QUANTITATIVE SCREENING OF POTENTIAL ENERGY-SAVING ECHNOLOGIES

A key part of this study was to identify new and/or less commonly used energy conservation technologies and evaluate their potential payback. The desire was to provide a reasonably comprehensive identification and screening process to allow the industry to work together to evaluate the best prospects for reducing overall energy consumption.

Identification of Potential Energy-Saving Technologies. A reasonably comprehensive list of available energy saving technologies was developed based on a generic industrial list prepared at Rutger's University. The basic list was taken from the "Assessment Recommendation Code System Version 8.2," August 2004, prepared by Michael Muller, Donald Kasten, and Fred Glaeser from the Center for Advanced Energy Systems, Department of Mechanical and Aerospace Engineering, Rutgers University. This was prepared in a program sponsored by U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program.

The basic structure and organization of this "Rutger's List" was maintained including the unique ARC Number assigned to each recommendation. However, in order to build upon this list in a way that was meaningful to the greenhouse industry, non-relevant or not applicable recommendations were omitted and additional industry specific technologies were added. This resulted in a modified list of over 200 available technologies for consideration.

Due to the generic source of the "Rutger's List," some of the identified available technologies are only loosely applicable to the greenhouse industry. In addition there is some apparent repetition in the list as different aspects of similar technologies can be applied to different classifications of operations (maintenance, production, etc.). While the modified list is not easily interpreted in the context of the greenhouse industry it is a useful brainstorming tool to take advantage of ideas and technologies applied in different industries.

Screening of Potential Energy-Saving Technologies. It would be impractical to perform a meaningful evaluation of all of the available technologies identified under this limited program. In order to better focus our efforts a preliminary screening and prioritization of these available technologies was required. The objective of the screening process was to eliminate those technologies already in place in the vast majority of facilities and to eliminate those technologies that are less practical and cost effective. A shortlist of the top 27 technologies was targeted to identify and evaluate the best options yet to be widely implemented.

To facilitate the preliminary technology screening, a semi-quantitative, numerical evaluation procedure was used. The first step was to identify (based on observations during the energy audits) whether each technology was already extensively used in most facilities (i.e., greater than 95%) or not. This would allow us to eliminate from consideration those cost effective options that were already uniformly utilized.

The second step involved assigning a relative numerical ranking to each of the technologies for each of the following criteria:

- Relative Capital Cost.
- Relative Operating Cost.
- Relative Annual Savings.

The relative rankings of the capital costs, the operating costs, and the annual savings are done on a scale of 0 to 5. A ranking of 0 corresponds to no costs/savings and a ranking of 5 corresponds to the maximum costs/savings.

The combined ranking is determined by applying a Weighting Factor (ranging from 1 to 3) to each of the ranking criteria. The combined ranking is determined by the following formula: (Capital Cost × Capital Weighting Factor) + (Operating Cost × Operating Weighting Factor) – (Annual Savings × Annual Weighting Factor). The lower the combined ranking, the better the potential payback for the identified recommendation.

Once this screening procedure was applied to the technologies, the 27 technologies with the lowest sum of ranking criteria that aren't already uniformly utilized were short-listed for further investigation. The following tables (Tables 1, 2, 3, 4) summarize the short listed energy reduction technologies under the basic categories of Boilers, Electrical, Insulation, and Other. This list has been published previously by Ag Energy Co-operative at the conclusion of the initial auditing program. Various technologies are presently being validated by Ag Energy in different commercial greenhouses.

Acknowledgements. This paper and the study it was based on would not have been possible without the vision, direction, and financial support of Ag Energy Co-operative and its Director Mr. Mike Bouk. The Geomatrix team was also fortunate to be greatly complimented by the talents and enthusiasm of Ron McDonald and his staff at AgViro. In addition to the crucial participation by Mike and Ron, I would also like to acknowledge the contributions of the following:

Technical Contributions: Theo Blom, University of Guelph; Wayne Brown, OMAFRA; Shalin Khosla, OMAFRA.

Audit Participants: Dodds Greenhouses, Nanticoke Greenhouses Ltd., Praills, Agriville Farms Ltd. – Plant 1, Ultra Grow, Agriville Farms Ltd. – Plant 2, Yoder Unit #3, Van Vliet Greenhouses, John Slaman Greenhouses, Maple – Inman Rd., Colonial Florists Ltd., Maple – Hutchinson, Seacliff, Del Sol Greenhouses, Silver Vase Greenhouses, Allegro Acres, Jem Farms Ltd., Colourful Gardens Ltd., TG&G Mastronardi, AMCO Farms Inc., Pointe West Produce, Sunrise Greenhouses Ltd.

Table 1. Boiler opportunity. They are chosen on the basis of applicability to the operations, payback and opportunity. Note that not all will apply to all greenhouses.

No.	Name	Description/reason for savings	Estimated annual savings on fuel bills (%)		Capital Cost and Payback	Savings
			Low	High		
1	Minimum size summer condensing boiler system and optional water storage tank	Small condensing boiler used to maintain main boiler(s) at a temperature slightly above ambient to prevent damage	2	10	Medium 2 years	By operating a small yet high-efficiency boiler for longer periods of time, the main boilers do not cycle on/off. This saves both operating dollars and wear and tear.
2	Economizers	Flue gas heat recovery for pre-heating water or heating spaces	7	13		Heat in the flue gases is recovered. There is significant heat in the gases in the form of moisture. When this moisture is condensed out, the heat is recovered for other uses instead of venting to the atmosphere.
3	Condensing boilers	92%–94% efficient boilers	8	10	Large > 2 years	Where heat is required and the boiler can be operated at a supply temperature if 65 °C or less, boiler operating efficiencies in the 93% range can be achieved.
4	Tune up and maintenance program	Rigorous inspections and tune-ups, documentation	2	10	Low < 2 years	Even small changes in efficiency due to dirt, and settings can cost significantly. This is one of the fastest paying, yet typically ignored, savings opportunities.

5	Servo controls	Separate air/fuel control	2	8	Medium 2 years	Many modulating boilers use a mechanical linkage between the air and fuel supplies. A servo control uses a digital controller and separates the two for more efficiency throughout the modulating cycle.
6	Flue stand by losses reduced	Flue gas control (Exhausto)	1	3	Medium 2 years	An Exhausto controller prevents excess (heated) air from escaping to the atmosphere from the boiler room, through the boiler, during boiler off times.
7	Stand-by boiler isolation	Isolate other boilers from primary boiler hot water	0.5	1	Low < 2 years	By creating isolation valves, hot water can be diverted from stand-by boilers until required. Mixing valves will be required to avoid shock.
		Totals	22.5	55		

Table 2. Electrical opportunity. They are chosen on the basis of applicability to the operations, payback and opportunity. Note that not all will apply to all greenhouses.

No.	Name	Description	Estimated annual savings on electric bills (%)		Capital Cost and Payback	Savings
			Low	High		
1	Power factor correction	Capacitors used to reduce the kW demand charges	0.5	20	Low < 1 year	Motors and transformers commonly cause a power problem called Power Factor. A PF below 0.9 will mean that the charges for demand (kW) will be increased; the poorer the PF, the higher a recalculated demand charge will be.
2	Demand management	Schedule electric loads to reduce peak demand charges	0.5	20	Low < 1 year	Demand is up to 40% of the charges for electricity. Most operations will be charged for demand if the service is 400 amps or greater. By regulating loads so they do not operate at the same time, significant savings for minimal cost can be achieved.
3	Lighting	Upgrade process, office, other non-growth light systems to EE fluorescent T8 and T5	0.1	5	Low < 2 years	Non-growth areas although not a large percentage, can offer savings and should not be overlooked. Anything from turning out the lights to automatically controlled variable output T8 fluorescent save dollars.
4	Energy efficient fans and optimum control	Energy efficient fans and staged control	0.5	30	Medium 2 years	Fan selection is difficult. New ratings systems by independent labs allow comparison using air flow rate outputs per unit energy input.

5	Variable frequency drive vs. 3- or 4-way mixing valve	Use of frequency drives on pumps with varying loads, includes heating and irrigation	0.5	5	Low < 1 year	Standard controllers use a continuously operating pump with a 3 or 4 way-mixing valve. Removal of the mixing valve and varying the pump flow rate with a VFD can save dollars.
6	Conversion to natural ventilation	Requires roof conversion, removal of exhaust fans	2	50	High > 2 years	Summer ventilation is the single highest cost (next to grow lights if present). By converting to natural ventilation, demand and energy costs are significantly lowered, along with security of ventilation during power outages.
7	Reduheat	70% infrared heat reflectivity roof coating	2	4	Medium	Coating is applied to roof and reduces heat caused by infrared penetration in summer, reduces ventilation requirements and thus increases CO_2 retention.
		Totals	6.1	134		

Table 3: Insulation Opportunity. They are chosen on the basis of applicability to the operations, payback and opportunity. Note that not all will apply to all greenhouses.

			Estimated annual savings on bills (%)			
No.	Name	Description	Low	High	Capital Cost and Payback	Savings
1	Insulation curtains	High R value of single curtains	5	10	Large > 2 years	Higher insulating value curtains will reduce heat loss. Black curtains should be avoided as well to reduce black body effect losses.

Table 3: Insulation Opportunity. (Continued)

No.	Name	Description	Estimated annual savings on bills (%) Low	High	Capital Cost and Payback	Savings
2	Insulation north wall	Insulate north wall with air bubble or air bubble/foil	0.5	4	Large > 2 years	No sunlight from the north wall so should be fully insulated; temporary low R bubble wrap should be used as a temporary measure.
3	Insulation side wall	Insulate west, east and south walls	0.5	4	Large > 2 years	In many cases, cold outside walls lower local productivity. Moveable curtains or potentially permanent insulation, foil backed bubble wrap can be used.
4	Insulation perimeter/ foundation	Install perimeter insulation to frost line	0.5	2	Medium 2 years	Insulating the first meter of wall height can save significant heat loss. During major renovations or for new construction, insulating below grade to the frost line can also pay off.
5	Insulation roof	Bubbles pumped between double poly layers	10	52	Medium < 2 years	Double poly systems can be retrofitted or built new with a liquid foam insulating layer between poly layers. Foam provides high R in winter as well as changeable 20 or 50 % shading in summer.
6	Two insulation curtains	Use of multiple curtains	5	35	Large > 2 years	Curtains used for shade have limited insulating value, but are designed for this purpose. By adding a second high R curtain (ideally that adds limited shading effect) significant savings can be achieved.
		Totals	22	109		

Table 4. Other opportunities. They are chosen on the basis of applicability to the operations, payback and opportunity. Note that not all will apply to all greenhouses.

No.	Name	Description	Estimated annual savings on bills (%) Low	High	Capital Cost and Payback	Savings
1	Ventilation and RH control	Optimized ventilation rate when used for RH control	0.5	2	Low < 1 year	When controlling for relative humidity, sensor calibration and controller settings have large impact on savings possible.
2	Seal leakage, glass and poly	Silicone, etc.	0.5	2	Low < 1 year	Facilities leakage (other than the main range structure) should be carefully evaluated for leaks, including around closed curtains, fan housings, doors, etc.
3	EFIN energy flow integrator system plus building model analysis	A program to analyze energy consumption by range/zone. Allows managers to correlate yields to energy consumption	0.5	5	Low < 1 year	This system measures actual energy input to a given range, allowing evaluation of temperature settings and other management changes, to actual heat input costs.
4	CO_2 recovery and hot water storage	Use of hot water storage system and day time CO_2 feed	2	10	High 2 years	By recovering heat and storing during non-heat times, the CO_2 can be used and the heat added later during cooler time periods.
5	Heat recovery	When using mechanical ventilation for humidity control, use of Heat Recovery Ventilator or Dehumidifier	2	10	High > 2 years	An air-air heat recovery ventilator recovers the heat in the exhausted air by preheating the fresh incoming air.

Table 4. Other opportunities. (Continued)

No.	Name	Description	Estimated annual savings on bills (%)		Capital Cost and Payback	Savings
			Low	High		
6	Heat system	Locate Heat system as close to ground as possible	2	5	Low < 2 years	Heat systems need to be as close to the plants as possible.
7	Temperature setting strategy	Cool day and warm night setpoint	1	3	Low < 2 years	Rest system to maintain average plant temperature over 24 h. Set temperature cooler in day when no insulation (curtains) in use and increase at night when curtains reduce heat loss.
		Totals	8.5	37		