ADAPTING TO CLIMATE CHANGE

04. EFFICIENT ENERGY USE

Summary

Mushroom farms and compost facilities are big energy users. On average, every tonne of mushrooms produced costs $533 in electricity. However, costs are higher for small operations. Energy costs may either increase or decrease in the future, depending on future government policy. Nevertheless, increasing energy efficiency has clear financial benefits for mushroom producers.

Opportunities to reduce costs include:

- Efficient cooling using centrifugal chillers and well-maintained evaporators, with multiple units installed so as to always operate close to capacity
- Refining cookout times and temperatures based on pest risk analysis
- Converting to metal shelf systems instead of wooden trays
- Ensuring insulation in rooms, vents and around doors is intact, sealed and dry
- Ensuring the facility itself is well insulated, walls shielded from the sun and shaded if possible, with a light coloured roof equipped with wastewater sprinklers for evaporative cooling
- Vacuum coolers for mushrooms, operated only when full
- Precise management of grow room environments
- Energy recovery system used to pre-condition grow room air

Load shedding by electricity providers can provide another cost saving opportunity; facilities are compensated if they switch to an alternate energy sources such as diesel generators or solar systems during peak demand periods.

Current practice

Electricity for cooling, heating and equipment is one of the biggest operating costs for both composting facilities and mushroom farms. Energy costs are generally highest during hot periods due to cooling requirements; several farms report increases of about 50% in electricity costs in summer.

Key energy uses on farm include:

- Cooling/heating of grow rooms
- Heat and steam generation during room cookout
- Cooling/heating of processing and packing areas
- Postharvest cooling and storage of mushrooms
- Running equipment such as forklifts, pumps, fans, belts etc.

Estimates of the electricity cost per tonne of mushrooms produced (from the farms surveyed) ranges between $393/tonne and $2,011/tonne, with a

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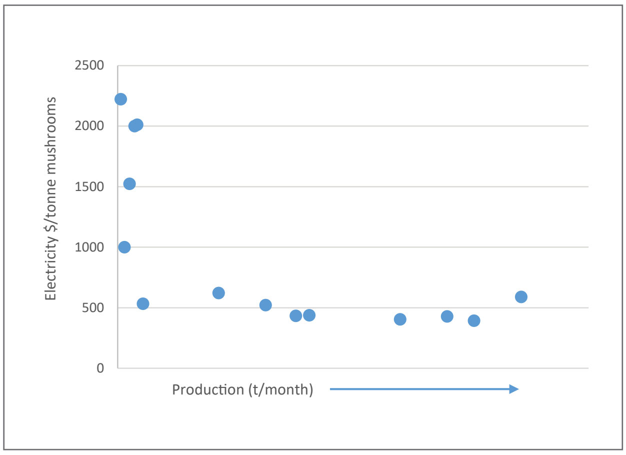

Figure 1.Cost of electricity per tonne mushrooms produced; each point is one farm. *AHR data*

median of $533/tonne. Small farms pay much more for electricity per tonne of mushrooms grown compared to large farms, even if they have installed solar systems.

Interruptions to electricity supply are a major risk, as even a relatively short blackout can result in total crop failure. Only five of the surveyed farms did not have backup generators, three of which were exotic mushroom producers.

Background

In 2017, the federal government commissioned an enquiry into the future security of the National Energy Market[1]. This was to consider the effects of government policy on the price and reliability of energy supplies.

There is much uncertainty about future policy in this area, which can change with an election, or simply party leadership. It may also change as Australia seeks to meet greenhouse gas reduction targets. Some scenarios considered were:

- Business as usual (BAU), with continued uncertainty over abatement policy and investment decisions
- A clean energy target (CET), where emissions targets must be met
- An emissions intensity scheme (EIS), where rewards and penalties are awarded to power generators based on emissions compared to an industry baseline

Perhaps surprisingly, energy costs are highest under the BAU scenario, primarily due to ongoing uncertainty about investment. It is expected that wholesale energy prices will rise gradually from 2020 onwards, plateauing about $90/MWh.

Wholesale prices are lowest under a CET scheme, followed by an EIS. This is because incentives provided to low emission energy producers entering the market puts downward pressure on prices. These reports suggest that electricity prices will continue to increase under current government policy. However, if a clean energy target is mandated, with or without a carbon price, then wholesale energy costs may fall.

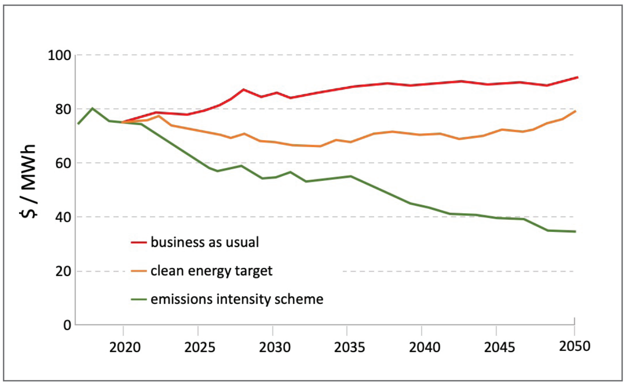

Figure 2. Estimated changes in wholesale electricity prices under different policy scenarios. Derived from: Gerardi and Galansi (2017)[1]

[1] Gerardi W, Galanis P. 2017. Report to the Independent review into the future security of the national energy market. 21 June 2017. https://www.energy.gov.au/. accessed 9-4-2020.

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Energy is a major cost to all mushroom producers. Rising temperatures are likely to increase costs further, as farms build in capacity for more frequent, extreme and lengthy heatwaves. If energy costs decline slightly, more efficient use of energy would directly improve farm profitability.

Efficient energy use

GROW ROOMS

Across all horticulture industries, there is an increasing trend to "Smart Farming" systems, where environmental variables are continuously monitored and, where possible, controlled. Mushroom producers are ahead of most other industries in this respect, as most farms already manage temperature, humidity and atmospheric composition with technology. However, there may be opportunities to refine growing systems further with new technologies.

Case study

In 2016 Premier Mushrooms in Colusa, California identified energy costs as a key restraint on further expansion. They invested several hundred thousand dollars in new systems to accurately regulate temperature, RH and CO_2. Room insulation was upgraded, more efficient lighting was installed and strip curtains and other related improvements were added to reduce energy use. They also changed the cooling method in the growing rooms to a centrifugal chiller from an air-cooled system. Centrifugal chillers are highly efficient, typically producing a cooling effect 2 to 3 times greater than the energy input[2]. These improvements allowed the farm size to increase by 33% without increasing energy costs[3].

Considerations for grow room cooling equipment:

- Flooded type evaporators have chilled water in tubes running through a jacket containing refrigerant, and are highly energy efficient
- Centrifugal chillers are usually most efficient when running at about 80% of full load; they are frequently inefficient when running at <50% of capacity
- Using multiple chillers allows units to be turned on or off, so all are running efficiently at close to capacity
- Increasing the chilled water supply setpoint to match cooling requirements can reduce power consumption by between 1.5 and 2% per degree
- Chiller condensers and evaporators require periodic maintenance to remove accumulated scale and annual "rodding" to ensure efficient heat transfer between the shell and tube

COOKOUT

Cooking out crops *in situ* at the end of their productive life is the most effective method to sanitise rooms and prevent spread of disease. Cooking out with the compost inside the room prevents spread of diseases such as dry bubble and cobweb to new crops within the facility. While cookout uses high amounts of energy, it ensures subsequent crops 'start clean', which is a fundamental of holistic farm hygiene, disease prevention and biosecurity (W. Gill, pers. com.).

How hot for how long?

There is limited data on heat tolerance for different mushroom diseases. Most data has been determined by lab-based trials, with a report by Overstijns[4] the key reference in this area.

This work did not, however, include green mould, which is far more heat tolerant than other pathogens. Rinker and Alm[5] found that *Trichoderma* could survive 74°C for 29 hours but was destroyed by 68°C for 42 hours. However, different species and strains of *Trichoderma* vary widely in their tolerance to heat, with

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2 https://electrical-engineering-portal.com/energy-efficiency-centrifugal-water-chillers
3 https://www.farm2ranch.com/articles/news/615/mushroom-farm-reaps-benefits-energy-efficiency/
4 Overstijns A. 1998. The conventional phase II in trays or shelves. Mush. J. 584:15-21.
5 Rinker DL, Alm G. 2000. Management of green mould disease in Canada. Mush. Sci. 15:617-623.

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PEST / PATHOGEN	KILL TIME (HOURS)			
	50°C	55°C	60°C	68°C
Most flies		5		
Nematodes		5		
Mites		5		
Cecids	1			
Cobweb	4		2	
Dry bubble		4	2	
Wet bubble	4		2	
Trichoderma			9 to >36	42
Bacterial blotch	0.17			

Table 6. Thermal death points of some common pests and diseases of mushrooms. Trichoderma (at right) is far more difficult to kill than other pests. From Overstijns (1998)[6] and Rinker and Alm (2000).[7]

some reliably killed by 9 hours at 60°C while others survived 36 hours at this temperature[8].

A wide range of time and temperature combinations for cookout are recommended in the literature. For example, Pyck and Grogan[9] recommend raising the compost to a minimum of 65–70°C for 8 hours, Beyer[10] suggests 66°C for 12 hours while Curtis[11] proposes up to 24 hours at 70°C.

If disease is severe, then the entire room may need to be steamed a second time after emptying. This second treatment can vary from 65°C for 2 to 8 hours[73] to 24 hours at 66°C[74] or even 6-12 hours at 75°C[75] if timber trays are present.

These treatments are far more severe than the combinations known to kill pathogens, as shown in Table 6. This is due to the large thermal load in the rooms themselves. This is particularly an issue on older farms, where heat loss through ageing door seals, walls and exclusion mechanics allows steam to escape, necessitating longer treatment times.

No matter how rapidly air temperature is raised, it takes about 14 hours for the substrate to reach 60°C[12], while timber trays can take five- to six times longer to heat than the substrate they contain[74]. Where farms have adopted heavy, deep dug peat instead of blonde peat it also takes longer to achieve thermal kill (W. Gill pers. com.)

Unfortunately, a number of researchers have concluded that sanitisers and fungicides alone cannot control mushroom diseases in compost, so frequent cook-out is essential[13].

Conversations with growers indicate that practices used on farms vary widely. While some farms do not cook-out at all, others steam rooms for 12 hours or more.

Reducing the energy needed for cookout

When deciding on the time and temperature combination to use, growers must assume a worst-case scenario, as they are unsure what diseases may be present. However, new molecular techniques allow much faster and easier detections of pathogens. Optimising the cook-out process, so sufficient heat only is applied to kill the pests present, could provide significant potential energy savings.

6 Overstijns A. 1998. The conventional phase II in trays or shelves. Mush. J. 584:15-21.
7 Rinker DL, Alm G. 2000. Management of green mould disease in Canada. Mush. Sci. 15:617-623.
8 Morris E, Harrington O, Doyle ORE. 2000. Green mould disease – The study of survival and dispersal characteristics of the weed mould Trichoderma in the Irish mushroom industry. Sci. Cult. Edible Fungi. 15:645-651.
9 Pyck N, Grogan H. 2015. Fungal diseases of mushrooms and their control. MushTV Factsheet 04/15. www.mushtv.eu
10 Beyer DM. 2018. Best practices for mushroom post-crop sanitation: steam-off/post-crop pasteurisatio
11 Curtis J. 2008. 2008-2009 mushroom production guide. Ministry of Ag. And Lands, Brit. Columbia.
12 Gill, W. 2018. Putting the heat on the cookout. Aust. Mush. J. Spring 2018: 39-43.
13 Baars J, Rutjens J. 2016. Finding a suitable biocide for use in the mushroom industry. Sci. Cult. Edible Fungi. 114-117.

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Testing for pathogens that are actually present in the room could allow growers to adjust cookout times and temperatures accordingly – but only if there is good information about the heat tolerance of these pathogens.

If floors do not reach high enough temperatures to kill all pathogens, they can be cleaned and disinfected further after the room is emptied. Trays can be treated with propiconazole (Safetray®) fungicide to ensure they are fully sanitised.

Cook-out energy requirements can also be reduced by more efficient growing systems. Newer mushroom farms use metal shelf systems. These allow spent compost to be removed directly from each growing room. If compost can be removed without diseases spreading to other parts of the facility, cook-out can be conducted after the room has been emptied. This reduces substantially the amount of energy required.

Even if compost is treated *in situ*, metal shelves heat much faster than wooden trays. Wooden trays are particularly difficult to sanitise, as pathogens can be harboured deep within the timber. Changing from wooden to metal systems reduces significantly the cook-out time needed to ensure proper sanitation.

In summary, the energy used for cookout may be minimised by:

- Ensuring all doors, vents and wall joints are well sealed and insulated
- Understanding what diseases and pathogens are present; times and temperatures required to control green mould are far greater than those needed to manage other diseases, which are in turn higher than those needed to control invertebrate pests
- Using a higher temperature with shorter duration where appropriate
- Changing from wooden to metal shelving
- Installing a belt system to remove compost directly from the room before cookout
- Combining cookout with cleaning and disinfection of floors, walls etc.
- Not allowing pathogen levels to build up that necessitate double cookouts

THE FACILITY

Systems such as **Profarm** (Denso Corporation, Japan) use many sensors installed across compost, power systems, atmosphere, ventilation systems, irrigation etc. to provide real-time tracking of growing conditions. This data is analysed by cloud-based software, correlating environmental changes with yield and quality data. Tracking inputs potentially allows the user to find efficiencies in energy and water use as well as optimising production.

Performance of cooling tower fans, condensers, water pumps, and air and water distribution systems can all be analysed to identify potential energy efficiency opportunities. About half the cooling load in inefficient buildings comes from solar radiation and poor lighting choices[14]. Mushroom farms have the

Figure 3. Galvanised belt and shelf systems allow more efficient cook-out than older wooden tray systems

[14] http://energy-models.com/hvac-centrifugal-chillers

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advantage of being windowless, while many farms have already installed energy efficient LED systems. Other improvements in efficiency may come from:

- Adding extra insulation to the roof
- Ensuring concrete floors are well insulated and sealed against moisture
- Checking for leaks that allow water to enter internal panelling; if insulation is wet it will be ineffective
- Light coloured roof coating to reflect solar radiation
- Spraying wastewater on the roof to provide evaporative cooling
- Maximising structural overhangs (eaves) on north facing walls
- Planting trees around the building to provide shade and evapotranspiration

Cooling

Many farms already use vacuum cooling systems to reduce the temperature of harvested mushrooms. While the capital cost of vacuum coolers is high, they are far more energy efficient than either forced air or room cooling systems. Nearly 100% of the energy used directly cools the product, instead of cooling air, cold room panels, fans, pumps, packaging etc. as occurs with forced air or room cooling. Vacuum coolers operate most efficiently when fully loaded; the same amount of energy is needed to cool a half load as a full one[15].

Figure 4. Room panelling materials that have become wet internally will not be effective insulators

Energy recovery

Energy recovery ventilators (ERVs) can provide energy savings in mechanical ventilation systems. They recycle energy from the building's exhaust air to pre-treat the outside air/ventilation air. This preconditioning of outside air reduces the load the heating, ventilation and air-conditioning (HVAC) unit must handle, reducing the required capacity of the mechanical equipment.

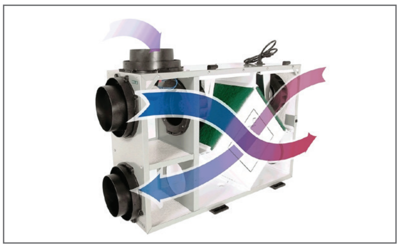

Figure 5. Energy recovery ventilators use exhaust air from inside the room to pre-heat or cool fresh air coming from outside the building. Picture by Greentek.[16]

Most heat exchangers are not sold as discrete units. Usually, they are factory installed as part of a packaged air handling system with fans, electrics, controls, casing, and a heating/cooling mechanism.

Mushroom growing rooms require a good air flow to maintain carbon dioxide concentration at a pre-set level. This makes it difficult to keep rooms at a steady temperature. Exhaust air is wasted heating or cooling energy. Most mushroom farms and composters in Australia have found HVAC cooling is their primary electricity expense.

There are a few types of energy recovery ventilators:

1. Fixed core plate: Exhaust and incoming air mixed through a matrix. Core plates are reliable because there are no moving parts.
2. Coils: Refrigerant or water is piped between the exhaust and incoming air ducts. Coils are hygienic because exhaust and incoming air does not come in contact.
3. Thermal wheel: A metal wheel rotates between exhaust and incoming air ducts. Thermal wheels are not always hygienic because some exhaust and incoming air is mixed. Thermal wheels are efficient

15 Thompson J. 2001. Energy conservation in cold storage and cooling operations. Perishables Handling Quarterly Issue 105. UC Davis.

16 Parry C. 2015. Fresh air without the heat loss (or gain). ReNew 127 (April-June 2014).

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at up to 80% recovery.

With a new HVAC installation, the reduced capacity requirements offset the cost of an ERV system. Texas A&M University calculated energy savings of 8.9-12.2% when combined with an ERV[17].

This is consistent with a local case study[18] in Coffs Harbour, NSW. The company reported an 11% cost saving in the HVAC system by combing a lower capacity air-conditioning unit with an ERV costing $12,500.

In another example, one Australian mushroom farm installed ArmCor ERVs at a cost of $8600 each plus GST. One ERV is installed on each growing room with 80sqm of beds. The ERV pre-heats or cools the incoming air by ±4.5°C. This allows faster reduction of CO_2 in each room by flushing, while still maintaining the set growing temperature. The devices also facilitate better control of humidity, providing significant benefits to the farm operation.

Load shedding

Load shedding occurs when there is extreme demand on the electricity system. It is most likely during extreme or prolonged hot spells, after storms or from infrastructure issues. Parts of the grid are shut down in a series of rolling blackouts to protect the remainder of the system from collapse. Essentially, load shedding occurs when supply cannot meet demand.

Peak demand for electricity tends to occur in the third or fourth day of a heatwave, as air-conditioning systems struggle to manage the accumulating heat inside buildings. Demand tends to be highest after schools and businesses return in mid- to late January, usually occurring between 5pm and 9pm on weekdays. While some of this demand can be met by solar systems, it generally occurs as output from these systems is decreasing, at the end of the day.

Normally increased demand within one state can be met by supplies from neighbouring regions. However, this is not an option during widespread heatwaves or other disruptive events.

In these periods, it is not unusual for the wholesale price of electricity to spike dramatically. Mushroom farms and composters with their own 100% backup power supply, whether a diesel generator or other energy source, are in an ideal position to capitalise on this. Large users can separate from the grid, effectively selling their demand reduction back to the grid. The supplier will be compensated for this, potentially at maximum grid price or 'spot price'.

This system provides further incentive for businesses to become energy self-sufficient during periods of peak demand. Not only does it avoid involuntary load shedding – a blackout – but provides a return on investment for energy generation systems. It also replaces the need for periodic generator tests, as they can be programmed to occur automatically as prices rise.

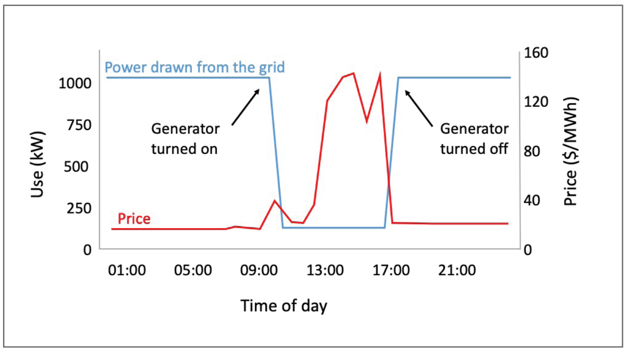

Figure 6. As spot prices for electricity rise, on-farm generators can be programmed to turn on. The system can then turn off again once prices return to normal levels, generating a significant return on investment for using this capability.

Derived from flowpower.com.au

17 Christman, K.D., Haberl, J.S. and Claridge, D.E., 2009. Analysis of energy recovery ventilator savings for Texas buildings.

18 Clarence Consultants ERV case study. Available at: https://www.clarenceconsultants.com.au/pdfs/mech_case_study_one.pdf

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