

# How much energy is involved in CO<sub>2</sub> enrichment?

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*Published in the Grower 61(11), 2006, p. 48-51*

Most greenhouse operators know their annual energy consumption, but have few details of how the energy is used. Knowing the breakdown of the energy consumption can help improving the energy efficiency. This article is about the amount of energy involved in CO<sub>2</sub> enrichment. It applies to greenhouses with natural gas as fuel, and with a buffer for heat storage. As part of a larger study we analysed heat flows and CO<sub>2</sub> flows. The result is not a straightforward recommendation, but a demonstration of the complexity of this subject. Recommendations can only be given on an individual basis after analysing the costs and benefits of CO<sub>2</sub> enrichment in a particular situation.

## **Method**

We did a case study as part of a project on energy in greenhouses funded by HortNZ and SFF. We determined the energy use for: (1) CO<sub>2</sub>, (2) CO<sub>2</sub> & heating, (3) heating alone. This was done by analysing the energy and CO<sub>2</sub> flows of a modern multi-hectare multi-compartment Venlo-type glasshouse in North-Auckland. The grower applies 'standard' CO<sub>2</sub> enrichment practices based on natural gas as well as a buffer for heat storage. The annual gas consumption was around 1300 MJ/m<sup>2</sup>/y, which is relatively low. The heat storage was set up as a 'closed buffer system' and had a volume of 140 m<sup>3</sup> per ha or 14 litres per m<sup>2</sup> greenhouse area. It was used solely for CO<sub>2</sub> enrichment. The data were 5-minutes readings of the control computer over the period 1 August 2004 until 1 August 2005. They covered many aspects of the burner, heating system, buffer, water flows, and CO<sub>2</sub> enrichment devices, as well as greenhouse climate and outdoor climate. Given that combustion of 1 GJ of natural gas produces 52.7 kg CO<sub>2</sub>, we calculated the various energy flows and amounts of CO<sub>2</sub> for every 5-minute period of that year.

## **Technical details**

The maximum CO<sub>2</sub> capacity was 68 W/m<sup>2</sup>, or equivalent 61 m<sup>3</sup> gas per ha per hour, or about 13 gram CO<sub>2</sub> per m<sup>2</sup> per hour. The CO<sub>2</sub> injection rate varied a bit, as was recorded by the computer. Generally in spring and autumn (when quite a bit of CO<sub>2</sub> and heat are needed), the CO<sub>2</sub> injection rate was maximum, and the buffer was filled completely. In winter, however, the CO<sub>2</sub> injection rate was often lower because a small amount of CO<sub>2</sub> is sufficient to maintain the required CO<sub>2</sub> level. In summer the CO<sub>2</sub> injection rate was often lower in order to spread the CO<sub>2</sub> over a long summer's day. (This is because there are limits to the heat buffer capacity and the heat demand at night).

## **Results**

There is not one simple result. The results from this case study are many figures and percentages, presented in graphs and table on the next page. Note that this was a specific situation. The energy consumption and CO<sub>2</sub> enrichment will be considerably different between growers, due to differences in geographical location, climate, greenhouse, computer, equipment, fuel, crop, planting date, control regime, etc. Therefore these results should be regarded as indications only.

### Course of CO<sub>2</sub>

Figure 1a shows the CO<sub>2</sub> concentration in a greenhouse with CO<sub>2</sub> enrichment. The CO<sub>2</sub> level is high at night and drops during daytime. Plants produce CO<sub>2</sub> at night, and absorb it during the day. CO<sub>2</sub> enrichment was able to lift the CO<sub>2</sub> level in the morning, but not in the afternoon due to venting. Figure 1b shows that the burner was burning steadily on a CO<sub>2</sub>-flame during the day. In the evening the burner is off, because heat is taken from the buffer (see Figure 1c). When the buffer is empty (about 3 am) the burner comes on again.

### General

- 1) The average CO<sub>2</sub> concentration (Figure 2, middle line) varied from around 400 ppm (in spring, summer and autumn) up to 600 ppm and more (in winter and spring). The minimum (lower line) was often as low as 250-300 ppm, and occasionally lower. The maxima (top line) were occasionally over 1000 ppm, especially in June 2005. This is a common pattern.
- 2) The gas-fired burner was 'on' for around 19-20 hours per day in winter (mainly for heating) and 12-13 hours in summer (mainly for CO<sub>2</sub> enrichment).
- 3) The CO<sub>2</sub> enrichment period varied from 7 hours per day in winter to nearly 12 hours in summer.
- 4) In the CO<sub>2</sub> enrichment period, the CO<sub>2</sub> injection sometimes stopped for instance when the set-point was reached (happens often in winter), or when the buffer is full (can happen in summer). So the duration of actual injection is shorter than the CO<sub>2</sub> enrichment period.

### Amounts of CO<sub>2</sub>

- 5) Total amounts of CO<sub>2</sub> generated per day from all gas burned (for heating and CO<sub>2</sub> enrichment together) varied from 131 g/m<sup>2</sup>/d (in February) to 268 g/m<sup>2</sup>/d (in August). So in winter twice as much CO<sub>2</sub> was generated as in summer. But not all CO<sub>2</sub> was used!
- 6) The annual total of CO<sub>2</sub> generated was 69.5 kg/m<sup>2</sup>/y. But not all CO<sub>2</sub> was used!
- 7) The amount of CO<sub>2</sub> injected for enrichment per day varied from 35 g/m<sup>2</sup>/d (in June) to 126 g/m<sup>2</sup>/d (in December).
- 8) The low amount injected for enrichment in June was partly due to crop changes, and partly due to limited venting in winter.
- 9) The high amount of CO<sub>2</sub> injected in December was due to high need due to CO<sub>2</sub> loss due to venting. CO<sub>2</sub> enrichment was possible thanks to the heat buffer.
- 10) The CO<sub>2</sub> injection in December (on average 126 g/m<sup>2</sup>/d) was equivalent to an average hourly rate of 10.6 g/m<sup>2</sup>/h in nearly 12 hours CO<sub>2</sub> enrichment period.

### CO<sub>2</sub> in percentages

- 11) In summer, the major portion of CO<sub>2</sub> was obtained while heat went into the buffer (see Figure 3). E.g. in February, the average CO<sub>2</sub> injection was 104 g/m<sup>2</sup>/d. Of this, 80 g (77%) was generated while the heat was buffered, whereas only 24 g (23%) was generated while the heat was used directly.
- 12) In winter, only a small portion of CO<sub>2</sub> generated was used for CO<sub>2</sub> enrichment, e.g. 19% in August (Figure 3 and Table 1, first line). This was due to two effects: in winter a lot of energy was needed for temperature control, and only small amount of CO<sub>2</sub> was sufficient due to limited venting.
- 13) In winter, the CO<sub>2</sub> injected came about equally from combustion for direct heat demand and combustion while heat was buffered. They each made about 10% of the total amount of CO<sub>2</sub> generated. About 81% of the CO<sub>2</sub> was not utilised. (Figure 3 and Table 1, first line).
- 14) In summer, the CO<sub>2</sub> that was generated was well utilised for CO<sub>2</sub> enrichment, e.g. 87% in January (Figure 3 and Table 1).
- 15) In summer, the major part of the CO<sub>2</sub> was produced thanks to the heat buffer. E.g. in January it was 69% of the amount generated (or 76% of the amount injected). The rest of the CO<sub>2</sub> was produced during direct heat demand.

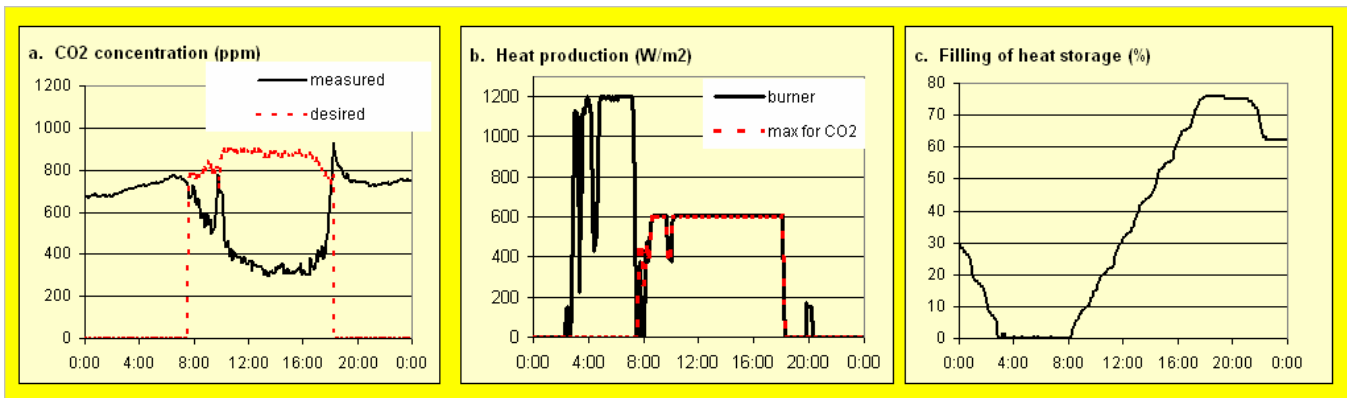
**Gas intake & heat storage**

- 16) The gas intake by the burner per day was double in winter than in summer (e.g. 5.08 MJ/m<sup>2</sup>/d in August versus 2.48 in January).
- 17) In winter, only a small portion of the gas combusted was used for CO<sub>2</sub> enrichment. In August, out of 5.08 MJ/m<sup>2</sup>/d combusted only 0.98 MJ/m<sup>2</sup>/d (19%) was used for CO<sub>2</sub> enrichment, and only 0.47 MJ/m<sup>2</sup>/d (9%) was stored in the buffer.
- 18) The gas intake used for CO<sub>2</sub> enrichment (and always also for heating!) varied from 18% in June to 87% in January, and was 45% on average over the year.
- 19) In January, out of 2.48 MJ/m<sup>2</sup>/d combusted, 2.16 MJ/m<sup>2</sup>/d was burned during CO<sub>2</sub> enrichment (87%). This is because combustion was concentrated in the daytime, so that the flue gases could be used for CO<sub>2</sub> enrichment. The heat was stored and used at night. This is typical for the summer.
- 20) Quite a big portion of the heat used in 24 hours was used at night, but generated during the day, with the use of the buffer. E.g. in January this was 1.71 out of 2.48 MJ/m<sup>2</sup>/d (or 69%).

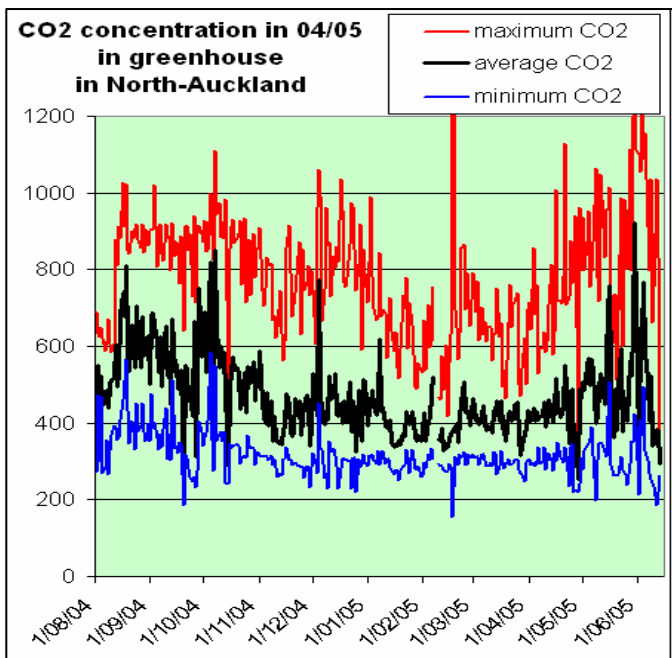
**Further work**

We are considering a new project focusing on CO<sub>2</sub> enrichment. This project should find answers to questions like: Is CO<sub>2</sub> enrichment in summer cost-effective? What level is optimal and profitable? What strategy should be used? Is pure CO<sub>2</sub> economically feasible in some situations? Ideas are very welcome.

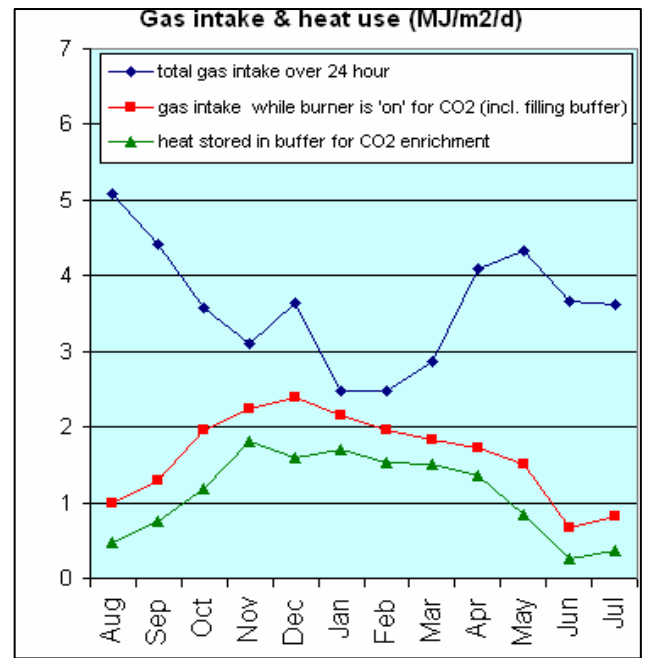
**Acknowledgements.** This case study was part of a project funded by HortNZ and the Sustainable Farming Fund.



**Fig. 1** CO<sub>2</sub> enrichment in a greenhouse in North-Auckland on 21 October 2004. (a) CO<sub>2</sub> level measured (—) & desired (---) both in ppm. (b) Heat production in W/m<sup>2</sup>. (c) Filling of buffer (%)



**Fig. 2.** CO2 concentration in ppm (minimum, average & maximum per day) at daytime (CO2 enrichment period).



**Fig. 3.** Average daily gas intake and heat buffering. Note: staggered crop change in June-July.

**Table1.** CO2 injected for enrichment, either during heat demand or while heat was stored in buffer. Also the percentage of CO2 emitted un-utilized. All expressed as % of total CO2 generation, all per day.

Month	Amount of CO2 generated by burner (over 24h)	Total amount of CO2 injected for CO2 enrichment	Part of CO2 injected while there was heat demand	Part of CO2 injected while heat went into buffer	Amount of CO2 emitted unutilized
	%	%	%	%	%
Aug-04	100	19	10	9	81
Sep-04	100	30	12	17	70
Oct-04	100	55	22	33	45
Nov-04	100	73	14	59	27
Dec-04	100	66	21	44	34
Jan-05	100	87	18	69	13
Feb-05	100	79	18	61	21
Mar-05	100	64	12	52	36
Apr-05	100	42	9	33	58
May-05	100	35	16	19	65
Jun-05	100	18	11	7	82
Jul-05	100	15	8	6	85
Year	100	43	14	29	57