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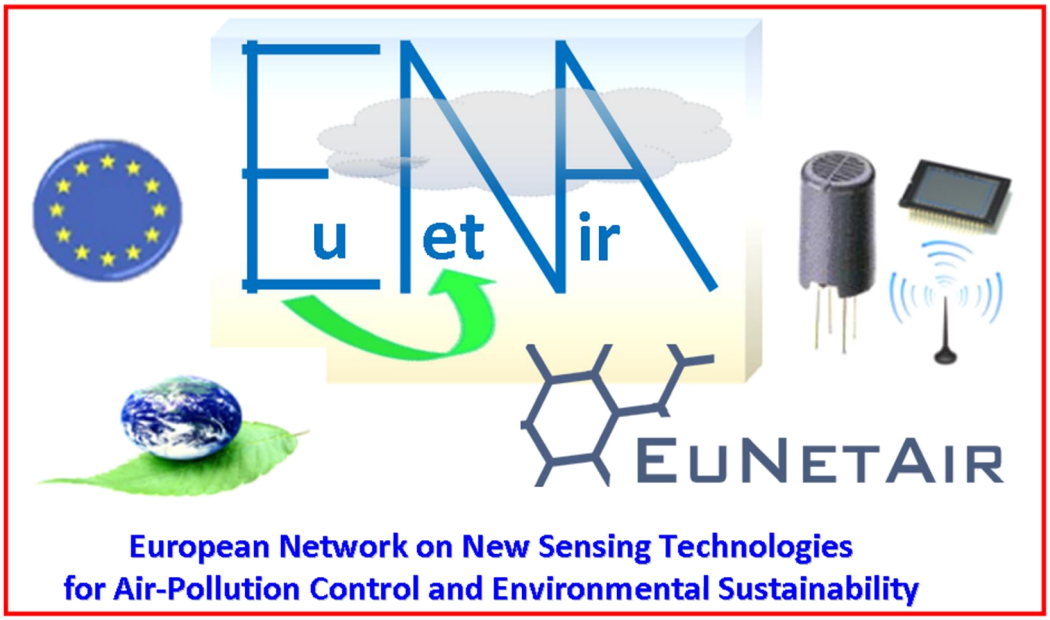
N Moser, J Saffell	IT, JB	2013-06-03	1.00	COST TD1105

COST EuNetAir WG4

CO_2 Application Summary



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CO_2 Application Summary, Content

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1 PROJECT SUMMARY

1.1 Result of project

Major carbon dioxide sensor applications are briefly described in this report divided into various ventilation, alarm, and biological applications. Also, we try to estimate the benefits in terms of

- Reduced energy costs
- Decreased events of death due to poisoning
- Fewer days at hospital intensive care
- Achieving a higher efficiency / yield for a particular application

Since the statistical data are uncertain these assumptions must be regarded as very rough estimates. However, it is clear that Europe as a whole could gain billions of EU if such sensor systems were implemented in the chosen application examples.

Obvious improvements for the society by using smart sensors, should be communicated to politicians and leaders in Brussels. We believe that the COST action EuNetAir, which is focusing on various air pollution measurement techniques, should promote the usage of smart sensor solutions and systems that would make an evident improvement when it comes to quality of life and economics.

1.2 Suggested improvements

Other EuNetAir targeting gases or major air pollutants should be investigated in a similar way. For instance PM (particulate matter), ozone or sulphur based compounds. Also, input from an expert within statistics, or more data, could heavily improve such reports.

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1.3 References

The report, data and calculations are saved at SenseAir AB, Delsbo Sweden. It is also available at COST TD1105 EuNetAir web page and partly at SenseAir web pages.

1.4 Revision history

Rev	Date	Characteristics
0.96	2013-03-13	First issue
0.97 - 0.98	2013-04-13	Revised, language checked
1.00	2013-06-03	Final version

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2 MAJOR CO_2 APPLICATIONS

On the following pages 14 main applications for CO_2 measuring devices are shortly described. Many of them are of course closely related to each other but since sensors / analyzers are somewhat differently designed concerning gas concentration span, temperature region, output signal functions, time resolution, etc, it is convenient to collect them under separate headlines.

There are some omitted CO_2 applications of minor importance from environmental or society point of view. For example

- CO_2 monitoring of the atmosphere, using weather balloons
- CCS (Carbon Capture & Storage) techniques
- CO_2 measurements near vulcanoes to predict activity
- COPD (Chronic Obstructive Pulmonary Disease) patients follow-up by CO_2 monitoring
- Fire alarm or presence indication by CO_2 level monitoring
- *etc*….

It is possible that some of these minor applications will be more important in future!

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2.1 Building Management System

With CO_2 measuring it is possible to control individual fans, dampers, valves, etc., creating a better indoor environment and energy savings. A common application is CO_2 Demand Ventilation in a Building Management System, controlling ventilation in rooms with varying numbers of people such as offices, classrooms, and cinemas. The ventilation control is normally based on both temperature and CO_2.

Why measure CO_2 for commercial ventilation?

The primary indoor source of CO_2 in office buildings is the breathing of the building occupants. CO_2 concentration in office buildings typically ranges from 390 to 2500 ppm.

Today there are laws about measuring the CO and the maximum allowed value is 35 ppm. Rules about measuring the CO_2 do not exist even if it´s equally as important. It is therefore useful to measure both gases to ensure personal safety.

The Threshold Limit Value for 8-hour time-weighted-average exposures to CO_2 is 5 000 ppm. The current American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) recommended minimum ventilation rate for offices is 10 L/s per person, corresponding to an approximate steady state indoor concentration of 910 ppm, based on the assumptions that outdoor CO_2 is 390 ppm and indoor CO_2 generation rate is 0.31 L/min-person.

Sick Building Syndrome (SBS) is used to describe a set of symptoms with unidentified etiology frequently reported by workers in office buildings. The individuals who suffer from SBS report that the symptoms occur when they spend time indoors, particularly in office buildings and that the symptoms lessen while away from the building. [1]

How does it work?

In order to have optimum ventilation it is important to use an affordable and stable sensor technology to measure CO_2 concentrations to determine the correct level of fresh air in a zone. Proper CO_2 measurements in a space make it possible to control the level depending on the person's air circulation at any given moment.

The sensor controls the need of fresh air in individual spaces and then sends a signal to a computer that controls the main ventilation system.

Complete air-handling and air-conditioning units help us create a better indoor environment as well as obviuos energy savings.

[1] http://senseair.hemsida.eu/wp-content/uploads/2011/05/6.pdf2013-02-26

Benefits?

- Public safety
- Energy saving
- Reduced costs
- Environmental savings
- Good indoor air quality

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2.2 Minor Ventilation Control

Either too little or too much fresh air in a building can be a problem. Over-ventilation results in higher energy usage and costs than are necessary with appropriate ventilation, but inadequate ventilation leads too poor air quality that can cause occupant discomfort and health problems.

Why measure CO_2 in buildings?

The value of carbon dioxide in the air can affect us a lot. The recommended indoor concentration of CO_2 is about 800 ppm. If it is lower, like 600 ppm, the room is over-ventilated, which is unnecessary and potentially costly.

The hygienic limit is around 5 000 ppm. At higher CO_2-concentration, about 15 000 ppm, it causes shortness of breath and raised heart rate. Concentrations of 20 000 to 80 000 ppm may cause convulsions, immediate paralysis and in worst case death.

How does it work?

The CO_2 concentration in a room varies depending of the number of people in it. An empty room generally has a concentration about 400 ppm (normal outdoor concentration), then the CO_2 concentration in the room increases for each added person.

Therefore using a small system of Demand Controlled Ventilation is good. This means that a sensor is measuring the CO_2 value, and it sends a signal to a ventilator or a VAV device (Variable Air Volume) that changes the level of the ventilation to the room.

Benefits?

- Energy saving
- Positive environmental impact
- Healthy indoor environment

The system has variable dampers that are usually used to regulate the air flow through the sensor.

For clarity we can say that a minor ventilation system is an intelligent sensor or analyzer which is adjusting one fan in the same room. This fan is regulating the air flow.

Reduced costs

This application saves a lot of money thanks to the energy savings, when a room is empty or just a few people in it, compared to ventilation with a constant air volume. This reduced use of energy is also very good for our environment and is an obvious way to conserve the earth´s resources. The indoor air gets healthier because many viruses and bacteria are disappearing. Also the number of particles that occur indoors are reduced by ventilating a room.

Tests of buildings that are using Demand Controlled Ventilation show that the energy costs are reduced by about 30%. This can lead to a return on investment in about 1 year. [1]

[1] PhD Hans Martin, CTO SenseAir AB, 2013-01-30

Energy Savings with CO_2 Control

The example is based on a small office

Yearly average outdoor temperature	8,0 °C
Inlet air temperature	17,0 °C
Energy cost (per kWh)	0,29 Euro
Projected maximum usage of the facility	18 h/day
Projected maximum occupation level	4 persons
Projected fresh air flow (per person)	8,0 litres/sec.
Actual average occupation level	2 persons
• Required air flow:	115 m³/h
• Required heating power:	372 Watt

Ventilation strategy:	Fixed	Occupancy control	CO_2 control
Yearly energy consumption:	3 262 kWh	2 447 kWh	1 223 kWh
Yearly energy cost *:	946 euro	1064 euro	355 euro

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2.3 Cabin Air

A cabin full of people can reach a high CO_2 level very fast. This leads to drowsiness and we don´t notice the increased concentration until we experience physical symptoms. The problem is the same in vehicles like trains, buses and airplanes. There are Climate Control Sensors that can monitor the CO_2 concentration in the cabin of a vehicle. At the same time the CO_2 measurement makes it possible to increase the efficiency of the air conditioning system. This gives a reduction in energy usage. [1]

Why measure CO_2 in cabins?

Car, subway train, and airplane cabins are becoming increasingly better sealed. The CO_2 concentration in a vehicle varies depending on the number of people inside. The concentration in a fully occupied cabin becomes critical fast, compared to an empty cabin for example. Therefore we have to ventilate.

People become tired or less focused by high CO_2 concentrations and therefore it can be a danger. In the case of a car driver falling asleep the situation becomes very serious.

It is also necessary to ventilate to ensure a healthy indoor environment in vehicles. There can be many people per m^3 in a small cabin like this. Bad air quality makes it more likely to catch viruses, bacteria and small particulates.

Freons and ammonia are the most used refrigerant systems, for example in cars. CO_2 is becoming preferable, because it isn´t combustible and it´s much less harmful to the environment. Of course any gas leakage has to be detected fast.

How does it work?

An empty vehicle has a concentration about 400 ppm (normal outdoor concentration). Then the CO_2 concentration in the car, airplane, subway or train will increase for each added person.

Benefits?

- Healthy cabin air environment
- Energy saving
- Positive environmental impact
- Reduced risk for driver drowsiness

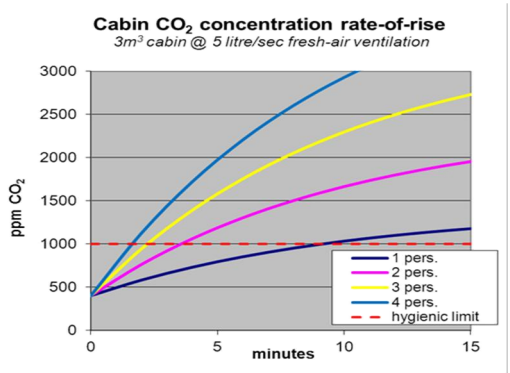
Therefore using a system of Demand Controlled Ventilation is best for efficiency. This means that sensors are measuring the CO_2 value constantly, and sending a signal to the ventilation system that changes the grade of the ventilation to compensate.

Reduced costs

Thanks to the reduced need of constant ventilation a Demand Controlled Ventilation system helps the vehicle to save energy. Engineers calculate the fuel savings of up to 10% when the system is operating in maximum cooling mode. [1] This is both money and environmental saving.

Well controlled ventilation makes the air healthier and this also saves money based on not having to send people to hospitals for cases of CO_2 poisoning or other air quality related illnesses such as asthma.

Less traffic accidents caused by drowsiness reduces the damage caused to people, roads, buildings etc. that can be destroyed in an accident.



*Despite normal **ventilation** the hygienic limit value is exceeded fast in a full car*

[1] http://www.bosch-press.com/tbwebdb/bosch-usa/en-US/PressText.cfm?nh=00&Search=0&id=302

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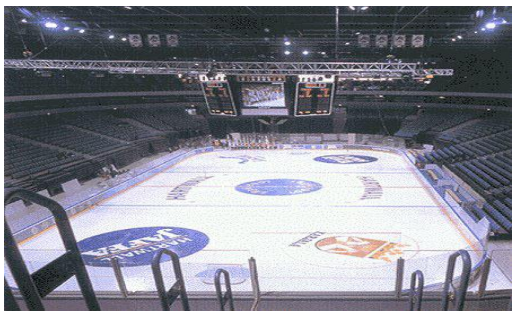
2.4 Ice Arena



There are thousands of indoor ice rink arenas in the United States, Canada, and Europe. The CO_2 value varies a lot in the stadium whether it is empty or at maximum capacity during a key match. Some arenas have bad air quality because of various pollutants. The concentration of pollutants mostly depends on the type of fuel in the ice resurface machine and on how much you ventilate. Therefore bad ventilation may be a health risk to both athletes and spectators. [1]

Why measure CO_2 in indoor ice arenas?

The value of carbon dioxide in the air in an arena may vary a lot. When the audience is large the value is higher than if it is in an empty stadium. Therefore we have to ventilate.

Without Demand Controlled Ventilation there is a potential to overventilate which leads to increased warm air into the arena, the consequence being the ice melts. To avoid this, the stadium then has to cool down the ice, which is energy-consuming.

It is also necessary to ventilate to ensure a healthy indoor environment. Machines in the stadium are polluting the air and there are many people in an arena like this.

How does it work?

The CO_2 concentration in an arena is varying depending on the number of people in it. An empty arena has a concentration about 400 ppm (normal outdoor concentration). Then the CO_2 concentration in the room will increase for each added person.

Therefore using a system of Demand Controlled Ventilation is best for efficiency. This means that sensors are measuring the CO_2-value constantly, and sending a signal to the ventilation system that changes the grade of the ventilation to compensate.

Reduced costs

Thanks to the reduced need of constant ventilation and the reduced need of cooling the ice, a Demand Controlled Ventilation system helps the ice arena building to save energy. This saves money and it´s also good for the environment. Estimated there are about 25 000 indoor ice rink arenas in Europe and therefore the savings will be huge.

Well controlled ventilation makes the air healthier and this also saves money based on not having to send people to hospitals for cases of CO_2 poisoning or other air quality related illnesses such as asthma.

An owner of an arena that starts using this kind of ventilation can expect a return on investment in around 3 months.

[1] https://engineering.purdue.edu/~yanchen/paper/2000-5.pdf 2013-01-22

Benefits?

- Energy saving
- Positive environmental impact
- Healthy indoor environment

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2.5 Garage and Tunnel

The modern range of vehicle engines emit many harmful substances, these include carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons and some 20 others. It is known that all engines produce CO particularly at cold start. To protect ourselves from this toxic gas, vehicles are installed with catalytic converters. Therefore, a warm running modern engine with catalyst generates 140 times more CO_2 than CO.

Why measure CO_2 in garages and tunnels?

Old vehicles (pre-catalyst) generate most of the carbon monoxide pollution, to solve this modern vehicles are installed with catalytic converters. Catalytic converters are not very efficient during cold start up but once warm they convert CO to CO_2 very effectively. This means modern engines emit much higher quantities of CO_2 than CO. It is wellknown that CO is extremely toxic but CO_2 in high levels is also hazardous to health. To ensure healthy air quality it is important to provide excellent ventilation, however running a ventilation system constantly is inefficient especially when few cars are running at a time.

In garages and tunnels, vehicles can be operating in both warm and cold conditions, therefore it is important to measure both gases to ensure a safe breathing environment. Today there are laws about measuring CO and the maximum allowed value is 35 ppm. There are currently no rules on measuring CO_2 but this is equally as important.

How does it work?

A meter can control, alarm locally, and be part of a larger complete system. This application has the same principal as required ventilation in classrooms for example.

The ventilation need depends on the number of cars running in a garage or tunnel instead of the number of students in a classroom. The sensors usually used to measure CO_2 and CO in public garages and tunnels are capable of covering an area of around 250 m^2.

Reduced costs

A study was made in a garage containing 77 parking places and covering an area of 1,445 m^2. The study showed that using sensors to control the ventilation reduced the fan operating time by 90% compared to constant running. The electricity cost was about 0.09 € per kWh (including energy tax and VAT) and the fan used 1.5 kWh in operation. This meant that the demand control solution produced an energy saving of 970 kWh, and a resulting reduction in running-costs of approximately 85 €/month.

If all residential garages were equipped this way, the sum of energy saved would make for a considerable benefit to society and environment.[1] A larger garage would have saved even more money thanks to the controlled ventilation system.

Another benefit is fewer people suffering from CO or CO_2 poisoning being admitted to hospitals. This helps reduce the costs of health care to the government.

[1] *http://senseair.se/wp-content/uploads/2011/08/E-TN-022.pdf - 2012-12-17*

Benefits?

- Public safety
- Energy saving
- Reduced costs
- Environmental savings

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2.6 Safety Alarm

We experience many situations daily that can develop into potentially lethal scenarios. Carbon dioxide gas can be considered harmless for humans and only harmful to the environment. However in high concentrations CO_2 can be fatal and very difficult to detect because it is odorless and colourless.

Why measure CO_2 to prevent accidents?

Measurements of CO_2 concentration in the air can **detect a fire** quicker and more accurately than the discovery of smoke or flames. It can be vital to alarm at an early stage, in order to prevent damage to the human body that can occur when you breathe in smoke. Normally, smoke consists of soot and asphyxiating gases.

For people to be able to work down in a mine a lot of safety issues have to be addressed. One of these safety issues is to **ventilate the mine**, there are many potential toxic and explosive gases in mining. If ventilation is poor, this can lead to carbon dioxide poisoning as CO_2 is a heavy gas and mines usually have a limited space. Measuring CO_2 in all areas by attaching portable alarms to the workers can detect dangerously high concentrations of CO_2 in time.

Using **kerosene heaters** in a small and tight room can be a great risk if the CO_2 concentration raises too much. There are small alarm sensors available that automatically shuts off the burner when the carbon dioxide level becomes dangerous, for instance above 7 000 ppm. A similar technique can be used for controlling small **ventless gas logs** or **alcohol-powered flueless fireplaces**.

For companies that use large tanks of CO_2, it is essential that there are detectors connected to these tanks to enhance safety and be able to respond quickly to a leak. Measuring the gas saves time and money for the company and provides a **safe working environment** for its employees. By monitoring CO_2 the environment is also protected from potentially large leaks of CO_2 into the atmosphere from unprotected bottles or leaks.

The volume of air in a vehicle is limited and in some cases it can lead to build up of high levels of CO_2. High levels this gas can cause drowsiness for the vehicle occupants which can lead to potentially major traffic accidents. This can be avoided by measuring the CO_2 that is connected to the air conditioner of the car, which will lead to **healthy air for the driver**.

In order to feel good and to perform at work, it is essential to have good ventilation. **Good ventilation** can be achieved by measuring the CO_2 concentration. For example, in classrooms where activity can vary it is essential for the ventilation to accommodate for that. If the sensor detects too high a level of CO_2 it automatically sends an alarm signal or adjusts the air setting.

Benefits?

- Energy saving
- Environmental protection
- Healthy indoor/ work environment

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2.7 Beer and Soda

In breweries CO_2 is added to soda and mineral water to get carbonic acid, H_2CO_3. It is done to make the soda feel fresher when we´re drinking it. Another good effect of carbonation is that it reduces the risk of bacteria in the drink. Carbon dioxide doesn´t affect the taste or smell of the drink and therefore CO_2 is also used as propellant gas for beer and soda at for example restaurants and bars. Today the CO_2 that is formed in the fermentation process in breweries is used to produce carbonated soft drinks. [1]

Why measure CO_2 at restaurants?

In 2011 a lady died at a restaurant in the USA. Also nine persons had to go to hospital after they had visited the toilet at the same restaurant. All this happened due to a leakage of carbon dioxide. CO_2 is a heavy gas and the toilets were at a low point in the building, therefore these rooms were filled with gas.

CO_2 is hard to detect with your senses and for that reason it´s important to always measure the gas where it´s a risk of high concentrations.

How does it work?

The recommended indoor CO_2 concentration is about 800 - 1 000 ppm. A somewhat higher concentration can for example cause headache and when it´s in levels up to 80 000 ppm it causes convulsions, immediate paralysis and in worst case death.

By continuous measurement of the air and a quick alarm at breweries, pubs, and restaurants there is no big danger. It does not have to be expensive to buy an alarm like this to make the personnel feel safe and not have to worry about possible leakages.

Reduced costs

Thanks to the measuring, society gets fewer carbon dioxide poisoned people at hospitals. This helps the government save money.

A big accident can be very costly for a company. The restaurant, in the example, had to close down while the police made a full investigation into the cause of the catastrophe. This is of course expensive both in time, money and reputation. The government has to pay to investigate if the accident was a crime or not. This is all very costly and totally unnecessary.

[1] *Handbok för CO_2 detektering. Behovsstyrd ventilation och industriella applikationer, CALECTRO AB, 2013-01-08*

Benefits?

- Personal safety
- Money saving

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2.8 Food Transportation and Storage

Research on gas concentration in food packaging has been going since the 1930's. It's proven that the control of surrounding gases, humidity and temperature within the food packaging can slow down the ripening process. It is now possible to better control decomposition and help prevent pathogens.

Why measure CO_2 in transportation?

The food stays fresh longer and has enhanced flavor under controlled conditions. This leads to reduced losses of the food, resulting in more food for minimal amount of energy.

The food can be **transported long distances** in a controlled environment. There's a positive environmental benefit as you ship with only fresh food so no need for costly freezing and thawing processes.

When you **control the growth process** it reduces the amount of food that gets wasted in the stores. The food producers also benefit from gas concentration measurement due to reduced losses in the supply chain.

Utilising a CO_2 controlled packaging method to increase shelf life of food products will result in less discarded food due to short expiration dates of uncontrolled packaged products.

Regulating the temperature and gas concentration in the air can slow down the maturing process without a need of using chemicals.

[1] *http://www.gardenguides.com/137125-fruits-vegetables-carbon-dioxide-storage.html 2013-01-23*

How does it work?

The reason why plant maturing rate slows down by increasing the CO_2 level, is because this gas inhibits the formation of ethylene in plants.

Small concentrations of ethylene have an effect on plant maturation rates to differing extents. The concentration of ethylene, which is coupled to the CO_2 concentration, also depends on temperature - if the temperature is low a low concentration of ethylene is required.

Oxygen levels of only 1% to 3% can destroy the microorganisms that cause decay.

Carbon dioxide levels of 60% combined with 1% oxygen are effective in killing insects that may be in leaves and stems of tropical fruits and vegetables, as stated in a report by Adel Kader. [1]

Product	Temp in °C	% relative moisture	% O_2	% CO_2	Ethylene	
					Expels	Sensitive
Banana	12-15	85-100	2-5	3-5	+	+
Bean sprouts	0	90-98	5	15	+	
Mushrooms	0-5	90-98	5	10		+
Tomato (ripe/green)	12-20	90-98	3-5	5-10	+	+
Tomato (ripe)	8-12	85-98	3-5	5-10	+	+
Cauliflower/broccoli	0-5	90-95	2	5	+	++
Cucumber	8-12	90-95	3-5	0		++
Head of lettuce	0-5	95	2-5	0		++
Capsicums	8-12	90-95	3-5	2	+	+
Grape fruit	10-15	85-90	3-10	5-10		
Peach	0-5	90	1-2	5	+++	+
Apple	0-5	90	2-3	1-2	+++	+
Pear	0-5	90-95	2-3	0-1	+++	+
Plum	0-5	90-95	3	8		+
Strawberry	0-5	90-95	10	15-20		

Benefits?

- More efficient and economical
- Reduced loss in the supply chain
- Enhanced flavours
- Increased shelf life
- Improved product quality
- Reduced need for chemical spraying

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2.9 Chicken Farming

It takes about 21 days to hatch a chicken and during that time, it is crucial that the surroundings are controlled for it to be successful. Egg hatching farms transform the chickens into "broilers" or egg laying hens. Meat from egg hatching farms is the most consumed worldwide.

Why measure CO_2 in chicken farms?

Less staff required to run the breeding stations thanks to all hatching around the same time. Easier to plan shipments and know how many birds can be transported at a time. This results in less capital and transport costs.

A smaller number of birds that die during transportation which delivers more profit per shipment and less feed losses.

More efficient and cheaper feeding options, both through feed reduction and reduction in time.

Faster and easier to slaughter the animals using CO_2 and there is no unnecessary suffering to the birds.

Packing method using CO_2, so **food will last longer** in supermarkets and for customers once purchased. This means a reduction in food that is discarded because of expiration dates.

How does it work?

The fertilized eggs are placed in a chamber/ machine, which then regulates the CO_2 content depending on what stage of development the eggs are in. The eggs that are alive contribute to the CO_2 development (not 100% of all eggs are alive), which means that you have to monitor the CO_2 levels continuously.

It has been shown that during embryonic development, the supply of CO_2 demonstrated positive health effects.

Control of CO_2 in chickens in development has also led to a more controlled hatching time.

The reason is the increased CO_2 concentration inside the egg, so the fully developed chickens start to hatch out of the shell. When this occurs, oxygen will be supplied.

Once the eggs are hatched, they are sent off into big trucks, where the birds continue to develop during the transportation. To be able to manage and stay healthy during the time in the truck the CO_2 is controlled for the whole journey.

It has been found that the bird's metabolism works slower at high concentrations of CO_2, which means it takes less time and less food to raise broilers or egg laying hens. That makes production cheaper for the companies, it´s also more sustainable to use less feed per pound of chicken.

The chickens are slaughtered by high levels of CO_2, which only takes a few seconds. This method is more humane than killing by electrical stunning.

Sustainability of the meat increases by 20%, when using CO_2 for modified atmosphere processing.

Benefits?

- Less staff
- Reduced losses
- More efficient and cost effective
- Faster and easier and more humane to slaughter
- Longer shelf life

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2.10 Mushroom Farming

The growing cycle in a mushroom farm takes about 13 weeks and consists of seven steps. First you make compost which is then heated up. In the third step the compost is mixed with mushroom spawns and put on trays. The trays are then cased with a layer of peat. In step five the first mushrooms appear and when the growing step is complete they are handpicked and weighed. After harvesting the compost is reused in garden mulch as an example. [1]

Why measure CO_2 in mushroom farms?

The value of carbon dioxide in the air is very important for growth in mushroom farms. Thanks to measurement of the CO_2 concentration we can adjust for the optimal rate of growth. Different CO_2 values also make the mushrooms incubate in different ways. One specific concentration makes the mushrooms grow wider, while another makes them higher.

Both temperature and humidity must be controlled during mushroom growth, depending on the different growth stages. The values for the CO_2, temperature, and RH are individual for different mushroom types.

How does it work?

CO_2 is a normal product of fungi metabolism and it´s one of the most important factors determining high quality and yield of edible fungi (e.g. button mushrooms). During the growth phase of the mushroom spawn a high concentration (10 000 to 20 000 ppm) of carbon dioxide is required.

When the mushroom growth becomes visible CO_2 concentrations of 800 to 1 500 ppm is an optimum level for growth and development, however there are some differences among the fungi types and the different stages of growth.

The details should be indicated by the producer of the mycelium. Generally, at CO_2 concentrations of less than 800 ppm, fungi are too small and numerous. Above 2 000 ppm, the quality of the mushrooms is poor (the stem is too long and the cap is too small). At CO_2 concentrations of 4 000 – 5 000 ppm mushroom development is inhibited. New mycelium begins to grow if the CO_2 concentration is higher than 5 000 ppm.

Reduced costs

Mushrooms that do not meet the quality requirements get discarded. When not controlling the CO_2 concentration in the air, the quality yield becomes poorer and for that reason it is more cost-effective to have control of the growth. Better control of the growing process of the mushrooms requires fewer resources to maintain.

[1] http://www.mushroomgrowers.org.nz/mushroom-growing-process.php 2012-12-05

Benefits?

- Optimal mushrooms
- Control in growth process
- Reduced costs

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2.11 Greenhouse

CO_2 is necessary for photosynthesis and thus essential for the growth of plants. Efficient CO_2 monitoring can optimize the growing period and increase profits. Different plants need different levels of CO_2 concentration to maximize development.

Why measure CO_2 in greenhouses?

It is essential to monitor the CO_2 value in greenhouses at all times because different plants have different needs. C3 plants cannot store all the CO_2 and transpire more as their stomata are open all the time. C4 is another kind of plants and these plants can store the CO_2 in its environment so they do not need to keep their stomata open. The third type of plant, the CAM-plants, can only take up CO_2 at night because their stomata are closed during the day.

It is important to have effective control of the ventilation for the growing plants to utilise the CO_2 to maximum effect without risk of damage, as shown in the figure below. Generally, the best effect is to distribute CO_2 to young plants and mother plants regularly and for all plants for a short period during spring. If the plant is sensitive it is extremely important to have pure CO_2, to prevent damage.

Up to 1 000 ppm CO_2 is estimated as a good level. If the levels of CO_2 are too high in the greenhouse, plants can be damaged. One cause is that they protect themselves by closing their stomata more than normal, which can result in damage to the plant in warm periods.
The content of CO_2 varies considerably over 24 hours. The reason is that levels as high as 500 to 1 000 ppm is dependent on plant respiration, which is usually higher during the night, regardless of the type of plant.

Benefits?

- Higher profits
- Less damage on the plants
- Shorter growing period

How does it work?

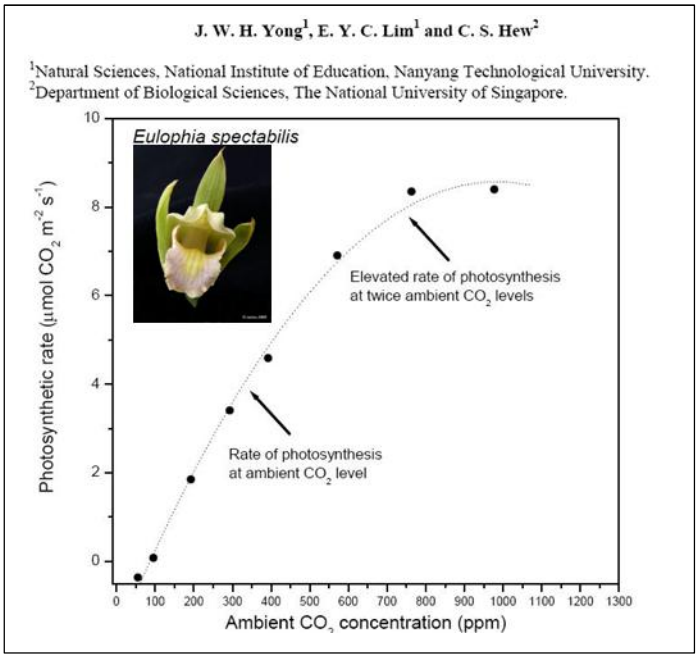
If all plants have the same conditions (including the CO_2 level) it increases the chances to harvest all at once and get similar results.

The annual consumption of CO_2 in a greenhouse is about 5 - 10 kg/m^2, only in exceptional cases does it take more.

Profit effects of CO_2 vary considerably. With tomato and cucumber they can obtain 8 -10% higher return.

According Crooks Hanks, M., Taylor, G. and Dolan, L., studies demonstrated CO_2 enriched plants produced more biomass than other plants. The fortified plants put their new biomass into the root, to be able to develop faster and become stronger specimens and contribute to the plant's reproduction. *[1]*

[1] http://www.co2science.org/articles/V1/N1/B2.php -2012-02-05



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2.12 Incubator

An Incubator can be described as an apparatus in which media inoculated with microorganism are cultivated at a constant temperature favourable to the growth of these microorganisms. There are big benefits by controlling the CO_2 in an incubator.

Why measure CO_2 in an incubator?

Incubators can be used in biology and microbiology, medicine, research and veterinary activities. They can also be used for quality control in the pharmaceutical, biotech, and even in the food and cosmetic industries.

Incubators can maintain constant temperature and concentration of the various gases such as the carbon dioxide (CO_2) and oxygen (O_2) content of the atmosphere inside. This creates a stable environment, which is needed to get as little measurement error and a high degree of accuracy as possible in a research study. If viruses or bacteria grow or multiply, it can be essential to know the ambient measurements for this to occur. There may also be a need for varied gas concentrations in the growing process, so as not to kill the microorganism.

How does it work?

An incubator is a zone that is shielded from the outside world. That makes it possible to completely control the environment inside the volume, regardless how the environment is outside the incubator.

To obtain the optimal cell conditions requires the right temperature, humidity and CO_2 concentration.

If you can control the climate in an incubator, it is possible to freeze, dehydrate and suppress research material, etc., to obtain the desired result.

Reduced costs

This application gives you a better control of the growing process thanks to the stable environment. Therefore the growing process can be faster and particularly have a high degree of accuracy.

If someone is doing a careful investigation the values of the measurements get a high accuracy. Therefore the research is more trustworthy.

Benefits?

- Growth control
- Research studies with a high accuracy

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2.13 Capnometry

When patients have a condition that is linked to breathing difficulties it helps to see the pulse frequency, which is possible by measuring the CO_2. These measurements lead to the right treatment at the right time and this leads to shorter recovery time for the patients. In addition, the most important improvement by capnometry is the reduction of the number of lost patients.

Why measure CO_2 in hospitals?

Less staffing is needed when monitoring the patient's breathing, by measuring the CO_2 it´s easier to determine if the patients can breathe on their own or require mechanical ventilation. This scenario leads to the reduction of staff, because you do not need to monitor the patient manually all the time.

Shorter recovery time is achieved when one uses a CO_2 measuring instrument that gives a better accuracy on what to add and how much, for the patient to recover as soon as possible.

Less loss of life in the hospitals

Individual-based treatments are possible since the accuracy of the CO_2 measurements can be made very precise from case to case. It leads to a better treatment for the patients.

The accuracy of medical care does not only lead to a faster recovery time, but it can also be crucial, since a wrong dosage to a very sick or vulnerable person can be fatal. So the **Individual-based treatments** are a big improvement since the measuring started.

When patients become healthier faster, this leads to shorter hospital time, which in turn leads to lower costs for both hospitals and patient. If the recovery period decreases, then the number of healthy people increases and also the amount of people that return to work, which benefits everyone.

How does it work?

A European summary states that “Respiratory diseases are after circulatory diseases and cancer, respiratory diseases were the third most common cause of death in the EU-27, with an average of 41.2 deaths per 100 000 inhabitants in 2010. Within this group of diseases, chronic lower respiratory diseases were the most common cause of mortality followed by pneumonia. Respiratory diseases are age-related with the vast majority of deaths from these diseases recorded among those aged 65 or more.

The highest death rates from respiratory diseases among the EU Member States were recorded in the United Kingdom (67.7), Denmark (66.5, 2009), Ireland (60.3) and Belgium (60.2, 2006).“ [1]

[1] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Causes_of_death_statistics/- 2012-01-16

Benefits?

- Less staff
- Less loss of life in the hospitals
- Shorter recovery time
- Lower costs per patient and time
- Safer treatments
- Individual-based treatments

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2.14 Flue Gas

Energy optimisation is essential to get as low operating costs as possible and at the same time benefit the environment in the best way. One way to do this is by careful exhaust gas monitoring to control burner processes in large power plants, garbage combustion appliances as well as minor heating systems in private homes. When burning fossil fuels, the largest part of the flue gas is CO_2.

Why measure CO_2 in flue gas?

Waste burning is mainly used to reduce the volume of trash, but now we also take advantage of the energy released during combustion. The exact garbage composition is of course hard to predict. Traditional fuels like hydrocarbons can also be of various qualities which makes it necessary to have a continuous exhaust gas sensor & control system.

By measuring the concentration of carbon dioxide it´s possible to control the process to obtain optimum extraction of energy, which is important considering that fuels can contain many different combustible substances in a varying ratio.

How does it work?

The flue gas can be extracted using a sample probe. The gas is then transported via a sample line, to a cooler unit fitted inside the analyzer, where the moisture is removed. The dry and cooled sample gas is then filtered to remove particulates before being directed into the measurement system, made up of pairs of sensors. Each sensor is fed alternately with sample gas and air. The sensors generate an electrical output proportional to a specific gas component.

What complicates the measurements in this application is the environment where the sensors are placed. Particularly the problems are that the sensors could be exposed to a high temperature and humidity and a corrosive surrounding environment. This requires an environmentally stable measuring device.

Handheld devices can also be used for this. An example is when a technician comes to a private home to check its heating system.

Reduced costs

This application has many benefits. It saves energy and therefore it saves both money and has a positive effect on the environment. This is possible thanks to the optimised combustion that we get by measuring the CO_2 concentration in flue gas.

This application also improves the safety and reliability, which may be a vital factor that makes people choose to install this kind of measurement system. A higher safety and less dangerous exhaust also lead to the benefit that fewer people are suffering from CO and CO_2 poisoning or other dangerous gases. This helps reduce the costs of healthcare for the society.

It is also easier to control combustion of various fuels such as waste or garbage, which usually is a big environmental problem.

Benefits?

- Optimised combustion
- Less dangerous exhaust
- Saves energy & money
- Easier to control combustion of various fuels such as waste or garbage

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3 ECONOMICAL SUMMARY OF CO_2 APPLICATIONS

3.1 European estimates

Below, we have chosen some evident application examples and summarised statistical data, in most cases from Sweden. Then, we extrapolate the data to be representative for whole Europe on order to emphasize the enormous savings in terms of for instance energy costs, hospital intensive care and human lifes, that such CO_2 sensor systems could create for the European Union. Based on statistical data we assume that the number of inhabitants in Europe are ~53 x larger than Sweden. For every presented example we underestimate and round the figures downwards.

The final result is presented below in 3.2-3.5.

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3.2 Ventilation control savings

There are five main applications within ventilation control systems as described above, see 2.1 – 2.5.

Assuming that 1 000 scyscrapes, 260 000 classrooms for children, 8 millions fresh cars (newly registered), 25 000 ice arenas and 25 000 in-door garages will have properly installed ventilations systems controlled by a number of small CO_2 sensors, the population and society in Europe will gain:

- 2 000 billion EU due to energy savings (heating or fuels)
- 200 less killed people, caused by asthma or car accidents
- 140 billion EU saving due to fewer hospital intensive care days

Of course these savings will also result in better environment due to cleaner European air and lower amounts of greenhouse gases, in particular CO_2, for the whole planet.

Application	**Chosen application example**	**Sites that could install CO2 sensor systems /Europe**	**Saved energy costs**	**Saved lifes**	**Saved Eu cost for patients which don´t go to health care / hospital**	**Comments**
2.1 Building Management System	Skyscrapes > 20 floors, 10 rooms on each floor	1 000	100 MEU			Assuming half of the skyscrapes hasn´t installed CO2 demand ventilation and that each floor has 10 offices
2.2 Minor Ventilation Control	Schools, assuming 5 classrooms in every school	27 000	670 MEU	100	70 MEU	Asthma among school children causes deaths and intensive hospital care
2.3 Cabin Air	Half of the new cars could get CO2 demand ventilation	8 000 000	1300 MEU	100	70 MEU	Driver drowsiness cause many car accidents - hard to predict exact numbers due to too high CO_2 level in the cabin
2.4 Ice arena	5% of all indoor sport arenas	27 000	4 MEU			Ventilation increase only when the Arena is full of people
2.5 Garage and Tunnel	Parking garages connected to housing estates	27 000	12 kEU			The more vehicles the more enhanced ventilation
Approximate SUM	Ventilation systems	8 000 000	2 000 MEU	200	140 MEU	

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3.3 Safety application savings

We have identified two safety alarm CO_2 applications, one is more general and the other directed to fixed installations at restaurants or pubs, see 2.6 - 7. Based on extrapolated figures of carbon dioxide poisoning in Sweden we guess that properly installed alarm sensors will gain:

- Around 50 less killed people in Europe
- 400 000 EU saving due to fewer hospital intensive care days
- A large but unknown saving (money) due to not loosing reputation for restaurants after tragic accidents

Application	**Chosen application example**	**Sites that could install CO2 sensors /Europe**	**Saved lifes**	**Saved Eu cost for patients who don´t go to health care / hospital**	**Comments**
2.6 Safety Alarm	Leakage from CO2 tanks	unknown	27	200 000 EU	Totally 3 injured/year in Sweden
2.7 Beer and Soda	Bars, Mac Donalds or similar with carbonating systems	1 000	27	200 000 EU	Totally 3 injured/year in Sweden
Approximate SUM	Safety applications	1 000	50	400 000 EU	

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3.4 Process control savings

The savings from the large number of process control applications facilitated by careful CO_2 monitoring as described in 2.8 . 2.14 are extremely hard to predict, due to lack of statistical data. At least 43 000 carbon dioxide analyzers could be installed in this type of application.

One can guess that container transports or modified atmosphere packaging can cause a few yearly deaths in Europe if the carbon dioxide concentration is not strictly controlled. In farming and incubator applications the yields will increase significantly, for instance tomatoes will increase their growth yield with 8 – 10% using CO_2 controlled atmosphere. In the case of careful capnometry the number of hospital intensive care days will decrease for patients. Flue gas control units will increase the burning efficiency and in the same time reduce the number of pollutants due to unsatisfying burning process.

Application	**Chosen application example**	**Sites that could install CO2 sensors /Europe**	**Comments**
2.8 Food and Transportation	Modified atmosphere packaging MAP	Unknown	Longer shelf life for packed food which gives less trash
2.9 Chicken Farming	Hatching control	16 000	
2.10 Mushroom Farming	Champignons	1 000	Yield increase and better shape
2.11 Greenhouse	Vegetables	25 000	Yield increase with 8 – 10%
2.12 Incubator	Laboratory use	Unknown	
2.13 Capnometry	Intensive care at hospitals	Unknown	Less hospital days
2.14 Flue Gas	Garbage burners	1 500	
Approximate SUM		43 000	

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3.5 Total benefit for Europe

If Europe installs 8 million carbon dioxide analyzers or sensor systems, the whole population and the surrounding society will gain a lot. Since there are cheap and reliable sensors available both from Europe and the rest of the world it is not a problem to find them. The cost for purchasing and installation is normally paid within 1-2 years.

Using underestimates the benefits for Europe could be as much as:

- 2 billion EU / year, by energy savings
- 200 unnecessary events of death / year
- 140 million EU saving / year due to less hospital days
- 8% yield increase in in-door farming applications