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Mitigating Global Warming and Climate Change with Design of Super Efficient Greenhouse

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Abstract*—*This study was conducted to design Super Efficient Greenhouse (SEG)and covers all aspects from growing food, combating global warming and climate change to regenerating environment. Today, many sustainable solutions can replace old unsustainable methods of building greenhouses and their unsustainableoperation.SEG offers better growing conditions, less energy consumption, less chemical inputs and above all, lower operating costs for greenhouse growers. This article presents our study on alternative greenhouse design, energy systems and construction options.Moreover, our basic model for backyard growers is publicly accessiblewhich is our contribution to the implementation of the Paris Agreement.

Keywords*—*Agriculture, Climate change, Design, Greenhouse, Permaculture, Sustainability.

I. INTRODUCTION

After adoption of the Paris Agreement at the COP21 on 12 December, 2015,in Paris, the whole world is urging to find solutions against climate change. United Nations agenda on climate change (goal 13 from Paris Agreement) includes listed facts about CO_2 emissions that increased by almost 50 per cent since 1990. Another fact is that emissions grew much quicker between 2000 and 2010 than in each of the three previous decades. [1]

To reach the goals of the Paris Agreement as soon as possible we have to be innovative and change practices. Sustainable designed Super efficient greenhouse meets a lot of those aims.

1.1. Energy

Greenhouses are used for year-round food production in temperate climates. If we combine data from Cornell University Agricultural Experiment Station and International Greenhouse Vegetable Production Statistics, we can see that greenhouse vegetable producers have energy consumption of 5208TWh of energy for heating and lighting in a year. This results in carbon emissions that are equal to those produced by driving around the world for 112 million times. It would take an area of healthy forest the size of India to offset that amount of CO_2. Moreover, approximately 1.18 Giga metric tones of CO2 emissions are produced every year. And statistics show that greenhouse area for vegetable production is expanding. [2],[3]

Many factors define energy consumption in the greenhouse, such as design, construction, materials used for construction, energy source used for heating, heating methods, crops grown inside. Considering these factors we can have major impact on energy consumption and global greenhouse gas emissions. [4] If we also add regenerative agricultural practices, we can even offset greenhouse gas emissions. [5]

On the other hand, energy costs of running greenhouses all year round are the third highest costs for the vast majority of greenhouse growers behind labor costs and plant materials. For example, energy costs represented over 10% of product sales in 2009 in the USA. This number will increase because of rising energy costs in the future, unless we do use better options. Heating energy of typical greenhouse growers represents around 75% of total energy consumption used for operating greenhouse production business. [4]

Within this study, a greenhouse design model was developed for commercial and noncommercial growers. It provides technical solutions that growers can benefit from, mitigate yearly expenses and offset CO_2 emissions.

1.2. Pest control

Greenhouse growers cope with the problem of pests in greenhouses. Pests are becoming more and more resistant to pesticides. On the other hand, we have environmental problems with overuse of phytopharmaceuticals. So a lot of growers are leaning toward natural solutions. For example, for insect pests they are starting to apply natural predators in their greenhouses. [6]

1.3. Environment

Due to the climate change, we are coping with harsher and harsher weather conditions. Hail storms can result in the loss of all products. Lost crops have also economic impact on farmers. [7]

1.4. Plant quality improvement

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Plants grown in closed greenhouses get lower quantities of sunlight radiation as those grown outside or without any kind of roof on top of them. In addition, almost all greenhouses filter UV radiation. [8] UV light pushes plants to synthesize secondary metabolites that protect plants from sunburn. Most of them are antioxidants (such as vitamins). More of antioxidants in the plant body more of them in our food. [8],[9]

Photosynthesis uses light to convert CO_2 and water into sugars and O_2. Greenhouses are built to be as sealed as possible. When plants photosynthesize, CO_2 levels drop and production sinks as well. That is why growers have to add CO_2 to offset production losses. That is the other expense to consider. [4]

1.5. Renewable construction materials

Most greenhouses are made from steel and concrete. These two construction materials have large embodied energy. [11] To offset that we should use alternative construction materials as much as possible. [11],[12]

II. LITERATURE SURVEY

A lot of new alternative solutions can be found in literature to solve the problem, sowe do not need to use old techniques and energy intense methods. However, there is not yet a single commercial solution to cope with all the problems.

2.1. Energy

Greenhouse growers can benefit and conserve some energy by simply having the greenhouse in the shape of a cube because cube's shape has the second smallest surface area for a given covered area and is also commercially interesting. The smallest surface area for a given covered area has hemisphere which is unfortunately not commercially practical to use. Greenhouse the shape of a cube has from 15 to 20% less surface area than freestanding longitudinal greenhouse for the same covered area. [4]

Furthermore, Sanford (2011) made a comparison of glazing material properties. If you use double-glazed solution, then polyethylene film with IR coat has the lowest heat loss characteristics (U-value of 0,5). Another great advantage of poly film covered greenhouses is that they can be better sealed than other types of greenhouses, according toSanford (2011). That means lower infiltrations rates and lower energy loses. [4]

Unfortunately, greenhouses with lower infiltration rates result in shortages in CO_2concentrations. [4] In such situations, growers add CO_2, as Sanford (2011) writes. [4] However, this means extra energy consumption for growing and extra costs for growers.

A simple step towards conserving energy is a method of heating the floor (or growing beds) under plants. This saves equivalently as much energy as if you turn down the thermostat for 2.5 to 5°C. [4]

In addition, energy can also be produced by compost and applied to different applications among which is greenhouse seedbed heating. [12] Smith and Aber (2014) claim that"The bio-oxidation of organic material that occurs during composting is an exothermic reaction that continually releases heat,…". [13] A large quantity of thermal energy is produced by composting but unfortunately, it is not used and it is lost in the surrounding environment as heat. [14] Recovery of different compost heat recovery systems was reviewed by Smith at al. (2016) who came to the conclusion that recovery rates averaged from 1895kJ/hr (1159kJ/kg DM) for lab scale systems to 204907kJ/hr (7084 kJ/kg DM) for commercial ones. [14] Compostpower.org (2017) estimated that you can get 30000kJ/hr from 30m3 of shredded bark mulch composting mound. [12]

Sanford (2011) reports that 25% of heating needs can be offset by active solar or subterranean heating. [4] Indeed, active solar heating can increase average soil temperatures during the coldest time of the year for 5 to 8°C. The optimum temperature difference between air temperature at the top of greenhouse and at the soil surface is 11°C in order to get the best results out of the subterranean heating system. [15]

To conserve energy inputs into greenhouse floor, you have to insulate foundations around greenhouse to about 1m depth. Moreover, Bill (1988) recognizes floor and earth beneath as critical heat store for cold month nights. He also explains that most of the subfloor heat escapes through surrounding soil and most of that loss occurs in the first 0.5m of soil depth. [16]

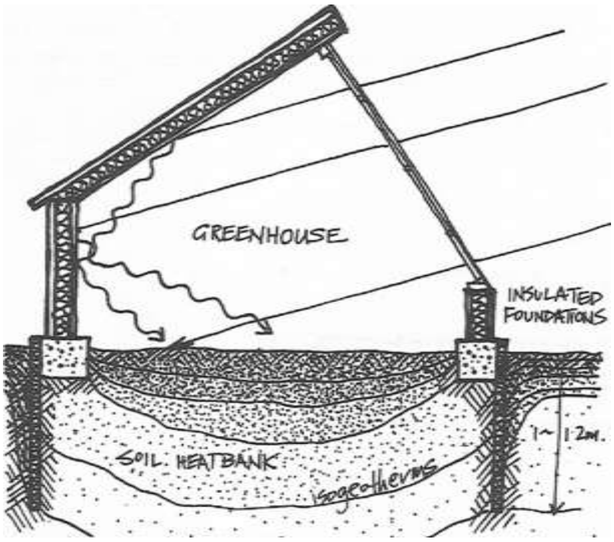

Fig.1: Difference in isogeotherms inside and outside greenhouse with insulated foundations (Bill Mollison, 1988: 416).

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2.2. Pest control

After Second World War growers in Europe have used a lot of chemistry inside greenhouses to eliminate pests and diseases. However, many authors, among them Lenteren (2000) claims that in our present time we have lots of possibilities to control pests with their natural enemies. [6]

Furthermore, another effective technique to combat pests and disease problems uses sunlight. In a study conducted by Nyeleti, at al. (2004), an effect of sunlight on the survival of *Salmonella* on surfaces conclusions were made, that sunlight exposure has the significant decrease in numbers of *Salmonella* on surfaces. [17] Another research proves sunlight to be effective disinfectant against tuberculosis and *E. coli*. [18]

In addition, Rodale Institute (2014) has outstanding findings. If compost is used as soil amendment, it increases soil biodiversity which suppresses soil born diseases and pests and helps with nutrient cycling. This soil benefits also improve productivity while reducing water and fertiliser needs. [5]

2.3. Environment

In 10-year trial Rodale Institute (2014) has proven that crop fields on which compost replaced synthetic fertilizer sequestered more than two metric tons of carbon, while conventional farming system lost carbon. [5]

In Slovenia, hail storms occur every year and the total devastation made between 1994 and 2008 was estimated at 260 million euros. [7] To get an idea how small Slovenia is, its surface area is only 20,273 km2. [19]

2.4. Plant quality improvement

If plants are exposed to direct sunlight or the whole spectrum (especially UV-B radiation) they increase the amount of active substances in their tissues. Among those active substances are also phenolic chemicals according toGaberscik at al. (2014) which have beneficial biological functions as antiviral, antibacterial, anti-allergic, anti-inflammatory, anti-carcinogenic, immune system-stimulating actions and other beneficial characteristics. [8] Moreover, human health can also benefit from these active substances because they lower the risk for cancer formation and cardiovascular diseases. [9]

Kitaya at al. (1998) find out that higher concentrations of CO_2 can compensate for lower light intensities. [20] As Singh at al. (2005) state,CO_2 is released throughout the whole composting process. [21]

2.5. Renewable construction materials

Wood as a building material is sustainable and renewable. Hanley (2015) states that 16% of all the fossil fuel in a year is usedfor manufacturing of concrete, steel, aluminum and brick from raw substances to construction products. [11] If we substitute these construction materials by using wood instead, we will save from 14 to 31% of global CO_2 emissions. [10]

III. SUPER EFFICIENT GREENHOUSE DESIGN

Our Super Efficient Greenhouse (SEG) embodies our research and work at Permaculture Institute Maribor. The design combines all known sustainable practices and some of our own research and findings.

We designed SEG to have least possible edge area to volume. The floor dimension ofour basic model for backyard growers is 4.5m x 6m and it is 3m high. The basic model for professional growers can be prolonged and/or connected with side walls, so you get gutter connected one.

Fig.2: Gutter connected greenhouse at our research facility.

Structural beams of SEG are all made from wood.

Double-layer poly film is used for roof and side walls. The foil consists of one continuous piece on each side. This enables growers to open their SEG all the way to the rooftop. On the upper end,a double-layer poly film is connected to roof ridge with foil fixation profiles and on the bottom end, it is clamped on steel tubing. This steel tubing can be rolled up the walls and up the roof all the way to the roof ridge. Both foils are welded togetheron side ends, so that air can be blown in between the foils. Air is pushed into steel ridge tubewith the help of a ventilator. This tube is perforated on the sides where the foil is attached and through that perforation air is blown in between double-layer poly film.

In addition, a layer of insect netting is placed underneath the double-layer of poly film. This netting is fastened the

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same way as the double-layer foil and can be also rolled up and down.

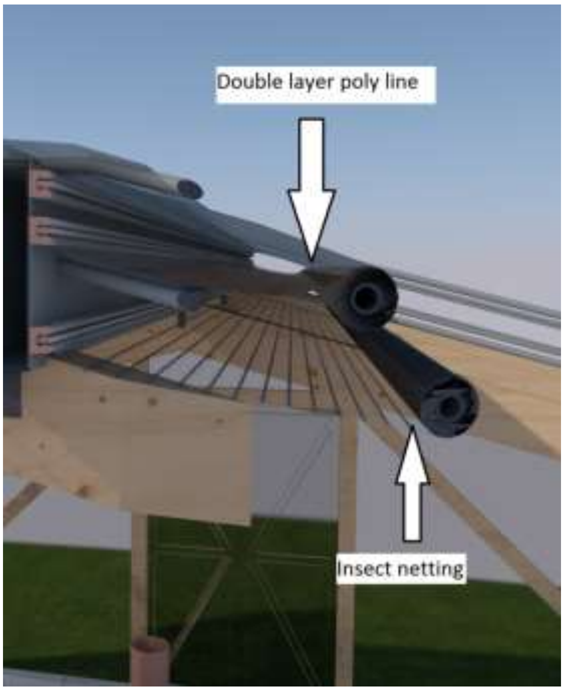

Fig.3: Double layer poly line and insect netting for roof and side coverage.

Furthermore, the front and back face of SEG is also glazed with a double-layer poly film which is also applied to the doors. In order to have a bigger entrance,doors can be folded.

A 10cm thick layer of insulation should be buried 1m deep all around the perimeter of the SEG.

Likewise, beneath the SEG floor, two types of tubing are buried underground. One type of tubing is 10cm perforated drain tile, located at two levels. Three of them are placed 30cm underneath the floor and other four are positioned 60cm underneath the floor. They are all connected to two 25cm tubing that goes vertical out of the floor. One of 25cm tubing is located at the front face of SEG and rises up to the ceiling of SEG. This one has also ventilator attached that blows hot air from the ceiling into the ground through buried tubing. Another 25cm tubing rises out of the ground beside back face of the SEG. This one looks out of the ground only by 50cm in height. This is the exhaust pipe of the subterranean heating system.

Another type of tubing are 16mm pipes for floor heating. They are located beneath the growing beds 20cm deep in the ground. Every growing bed has its own pipe loop and distribution cupboard is located on the side of the compost heap. All pipe loops are connected to this distribution cupboard and from here on one pipe loop goes into the composting heap. Flow pump which drives this system is installed inside distribution cupboard.

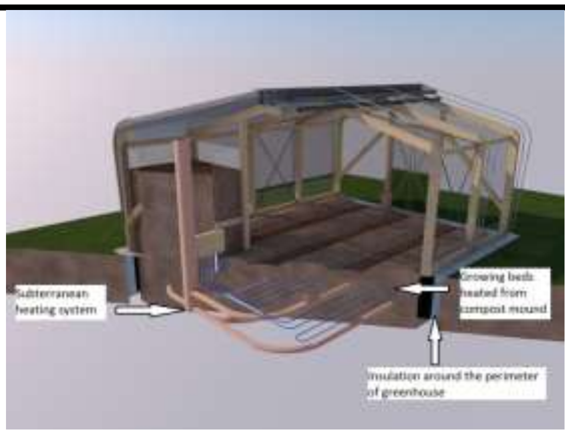

Fig.4: SEG alternative heating system.

Composting heap area is located at the front left face inside the SEG. The perimeter of the heap area is covered with wire mesh. The area devoted to compost heap is between two beams and measure 1,5m x 1,5m. The height of the perimeter wire mesh goes to 2m.

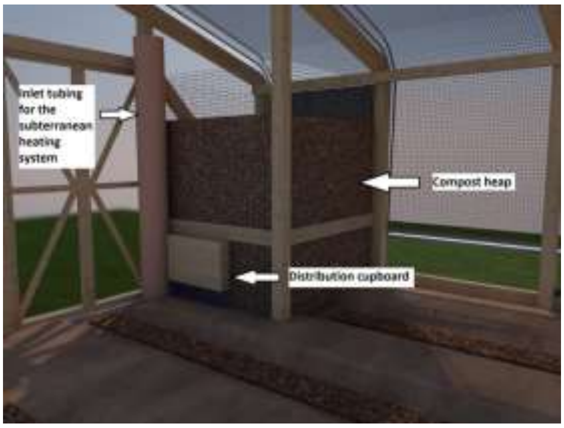

Fig.5: SEG from inside with composting heap.

IV. DISCUSSION AND CONCLUSION

In general, greenhouse production is expanding, so we have to use at least sustainable, if not regenerative solutions to overcome climate change. SEG design can cope with a lot of factors that defines energy consumption in greenhouse production. As energy consumption decreases, growers can expect lower operating costs, meaning faster refund of investment and higher living standard.

SEG construction is designed to be made from wood. So we encourage and prefer builders of SEG to use wooden beams. Beams made from wood can be made by anyone who has or learns few skills of carpentry. What is more, wood is available almost anywhere where greenhouses are used and it is renewable. During SEG lifetime enough wood can grow to replace its structural beams over time, especially if durable wood will be used such asRobiniapseudoacacia.

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Our personal observations and research on how much space does one family of four need to produce year-round vegetables, we designed our basic SEG model to be practical to use and as close to the shape of a cube as possible. We would like to minimize surface area to volume ratio to conserve energy losses with poor shape design.

The whole SEG is covered in double-layer poly film envelope to conserve energy losses compared to one layer glazed greenhouses. Poly film is used also because it can be rolled around round tube which serves to open side walls and rooftop. Additionally, our observations in practice show that inflated two-layer film greenhouse stands harsh weather conditions better than single poly film ones. According to studied literature, poly film greenhouses are also better sealed which conserves energy losses to outside environment as well.[4] This could have negative effects on plant growth because during photosynthesis CO_2 concentrations can decline inside the enclosed environment. This has been elegantly solved by putting compost heap inside SEG construction. During microbial decomposition of organic matter, CO_2 is released from the compost heap. In winter months with lower light intensity, higher concentrations of CO_2 can have positive effects, which can be seen in increased crop production.

Even more benefits are recognized by positioning compost heap inside the greenhouse. If you are using compost heat to warm your greenhouse, some heat is escaped directly from the surface of the heap. If it is positioned outside the greenhouse, the heat goes to surrounding environment. Also, some heat losses occur during transport of heated fluid in pipe lines going from compost heap to greenhouse floor heating system. The heap inside helps you to conserve such losses. Another thing to consider is finished compost that is used as growing amendment in the SEG and therefore should be as close to growing beds as possible. You conserve energy of transporting the medium. The compost is also rich in life and carbon. With amending more living creatures to your grow beds, you enhance soil health, plant health and eventually human health. Agricultural wastes are used to construct compost heap and not burnt or discarded in waste streams. By doing so, you put carbon in soils and decrease carbon emissions into the air. However, compost heap occupies some space in the greenhouse which can be otherwise used by growing. This could be mitigated if growers use the surface area of compost heap as vertical growing space, for example, to grow strawberries in pots on heap sides. Composting heap sides are in wire mesh which functions to contain composting material from falling off the sides of the heap.

Primarily compost heap is used to heat SEG growing beds. Growers havethe advantage to grow different crops on different growing beds because every growing bed has its own pipe loop. This way temperature underneath each crop can be adjusted to desired range. More research has to be conducted at this point to see if you need an extra heating source for growing in the coldest months of the year or there is enough to use heating with compost heat and subterranean heating system in SEG.

Subterranean heating system is another alternative heating system in SEG. It uses excess solar heat trapped in SEG and puts it into the ground. Because the ground is insulated on the perimeter of SEG, earth inside it acts as a thermal battery. Over the day you charge the battery with heat and over the cold nights, the heat is slowly released, to heat SEG space. The ground in the SEG is insulated to minimize heat losses to surrounding outer soil. Without a subterranean heating system, you have to ventilate greenhouse to push excessive heat outside of it, which consumes extra energy.

In summer months when you donot need to heat greenhouses and a subterranean heating system is also not enough to cool down inside temperatures, SEG is designed to open its side walls and rooftop. With that characteristic, the whole hot air from inside the SEG goes out. Also, beneficial UV radiation can hit the inside surface of SEG. So, there are again some positive effects of the openroof. Less energy is used for ventilation, less sanitizing chemicals have to be used because of the sanitizing effects of UV light, fewer chemicals used for combating with pests and diseases because of health-boosting effects of UV light on plants and as so, fewer pollutants in groundwater, plants synthesize more secondary metabolites which means healthier food for humans.

An open greenhouse is also an invitation for outside insect pests to come inside. Some growers use insect predators as the control of insect pests. But those predators could escape if the greenhouse is opened. To cope with both problems SEG has the second layer over the roof and sides which can be opened and closed as desired and consists of insect mesh. This mesh can also be used as hail storm protection in summer months and as shading cloth.

Our further research would be in regenerative agriculture practices, gathering of real data from operating SEGs in fields and calculating the energy consumption of SEG operation. A lot of climate problems can already be addressed with SEG design. Furthermore, SEG design and regenerative agricultural practices could help to reverse climate change.

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