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A modelling methodology for assessing use of datacenter waste heat in greenhouses

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Abstract

In Sweden, the number of datacenters establishments are steadily increasing thanks to green, stable and affordable electricity, free air cooling, advantageous energy taxes and well-developed Internet fiber infrastructures. Even though datacenters use a lot of energy, the waste heat that they create is seldom reused. A possible cause is that this waste heat is often low grade and airborne: it is therefore hard to directly inject it into a district heating system without upgrades, which require additional energy and equipment that generate extra costs. One option for reusing this heat without needs for upgrades is to employ it for heating up greenhouses. But assessing the feasibility of this approach by building physical prototypes can be costly, therefore using computer models to simulate real world conditions is an opportunity. However, there is a lack of computer modelling methodologies that can assess the possibility of using waste heat from datacenters in greenhouses in cold climates.

The objective of this paper is therefore to propose such a methodology and discuss its benefits and drawbacks in comparison with other research studies. This methodology combines computational fluid dynamics, process modelling and control engineering principles into a computer model that constitutes a decision support system to study different waste heat and greenhouse or mushroom house scenarios.

The paper validates the strategy through a case study in northern Sweden, where we assess the amount of produced waste heat by collecting temperature, relative humidity, and fan speed data for the air discharged from the datacenter.

The resulting methodology, composed by conducting measurements and computer models, calculations can then be used for other datacenter operators or greenhouse developers to judge whether it is possible or not to build greenhouses using datacenter waste heat.

Keywords: Computational fluid dynamics, cooling, datacenter, measurements, simulations, waste heat recovery

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1. INTRODUCTION

In the digital age of today, also known as digitalization, with cloud-based solutions and wide use of social media, the number of datacenters is increasing to handle the new demands on information storage. Datacenter servers consume a lot of energy and generate a lot of heat so these servers need efficient cooling solutions to not overheat. This has attracted datacenter operators to northern Europe since the opportunities for free air cooling by using the outside air are favorable. Other aspect like stable green electricity, robust digital infrastructure and reasonable energy taxes are also reasons. There are examples of research aiming to make datacenters more energy efficient such as the FIT4green project, [1], where the energy need for the automation technology was focused and the GAMES project, [2], where developing smart datacenters to decrease energy need was is focus. There are studies on how to absorb the heat during the cooling of the servers, e.g. [3], but to the authors knowledge, studies on how to use or reuse the heat from the datacenter ventilation systems are lacking.

Although newly built datacenters use technology that allow for using server heat for heating up the building there are still waste heat being let out to the free air. There is a challenge to use this waste heat that is usually low grade, up to 30-40°C although there are examples of such technology [4]. Ward et al [5] presented an approach that decentralizes the datacenters into nodes and where the waste heat from each node is used for heating adjacent buildings or facilities. We see a need of tools that help evaluating the opportunities for using datacenter waste heat in greenhouses. Therefore, we started a project in collaboration with many stakeholders within the energy, datacenter and food growing area, which is presented in this paper.

2. THEORETICAL FRAMEWORK

2.1. *Process modelling*

To model the heat transfer solution between the datacenter and greenhouse the process simulation software such as aspen plus, [6], can be used. Aspen plus uses basic engineering relationships and mass and heat balance to determine the outputs for the system. By varying some specific design parameters of the heat transfer solutions, correlations can be obtained that can be used for greenhouse dimensioning.

2.2. *Computational fluid dynamics*

With computational fluid dynamics (CFD) it is possible to numerically retrieve information about airflow and temperature inside a greenhouse [7]. The detailed knowledge provides the possibility to evaluate designs prior to construction but it is at the same time crucial that the models are set up with quality and trust in focus. The heat transfer situation of a greenhouse is complex with the joint effects of sun radiation, heat radiation, ventilation, external convection and conduction, heat transfer through the ground, condensation at the walls, leakage of air etc. The conditions inside the greenhouse are furthermore subjected to transient variations with regards to external conditions such as time of day, time of year and current weather situation. In this context, CFD can be a valuable tool in the assessment of external heat sources, e.g., the waste heat from a datacenter.

2.3. *Control engineering related modelling*

Solving a control problem (in terms of deciding how to steer actuators like ventilation, heating and cooling units based on current measurements from the plant) may benefit from the knowledge of mathematical models of the plant itself. If available (and with the caveats written below), models may indeed be used to forecast what will be the outcome of taking a specific control action. This means that (at least theoretically) models may enable choosing the current action as that one that leads to the “best” forecasted performance (with the metric “best” to be opportunely defined).

This paradigm is known as the predictive-control paradigm [8]. Implementing it, nonetheless, requires sufficiently lightweight mathematical models: since the control-decision problem should be taken “now”, the system needs to compute forecasts of the future outcomes sufficiently fast. This means that CFD tools - typically computationally intensive - are in general not suitable for implementing predictive control schemes.

Obtaining control-oriented models can then performed in different ways: one is to derive simplified descriptions (typically in terms of ordinary differential equations) using first-principles and physical knowledge of the plant. Another one is to employ data-driven approaches, where past measurements from the plant are used to compute statistical estimates of the inputs-outputs map (an operation that is often referred to as the "identification" of the system). Notice that often these two paradigms are blended into so-called "grey-box" modelling strategies where the structure of the model is fixed using first-principles, and then the parameters of this model is then populated using measurements from the plant and opportune statistical estimation algorithms).

Using a data-driven approach typically leads to more accurate models than using just first-principles and physical knowledge. In the case described in this paper, nonetheless, the plant needs still to be built, so actual measurements are not available. Our approach to perform control-oriented modelling of our data center - greenhouse system is then to follow a hybrid approach: if a CFD model is available, then the CFD simulator can be used as a virtual plant to obtain virtual measurements. This eventually allows using classical system identification strategies to obtain a control-oriented model; this control-oriented model then is used to design a plant control algorithm, and finally this controller can be embedded into the original CFD model so to perform a virtual feedback loop.

3. METHOD

3.1. Case

The municipality of Boden in northern Sweden wanted to study the possibility to use waste heat from datacenters to heat up greenhouses. They need a new greenhouse for growing park flowers and plants but they also see a need in creating educational possibilities and activities for immigrants as well as providing space for commercial actors to grow food or other crops. Hydro66 is a datacenter operator in Boden that was interested in participating in the study, see Figure 1.

Figure 1. The Hydro66 datacenter in Boden.

3.2. Measurements

Figure 2. Sensors for measuring temperature and humidity was mounted outside the outlet fans (left part) and on the inside of the outer wall (right part) to measure the incoming air.

Seven sensors, two measuring both temperature and relative humidity and five measuring temperature, were mounted at the Hydro66 datacenter in Boden. One of them was mounted on the inside of the outer wall, which is a wall with lot of small holes where outside air easily can come through, to measure temperature and humidity, see right hand side of Figure 2. The six other sensors were mounted as shown in the left-hand side of Figure 2. The temperature was logged from July 2016 until April 2017.

3.3. Model development

To determine the mass flow of hot air from the datacenter a process simulation model was created that is presented in Figure 3. The model consists of the air flow into the datacenter, the computer load that is represented as a heater in the middle and the airflow out from the datacenter. Also, some of the air is recirculated and mixed to create more stable condition inside. The inputs to the model is the outdoor temperature and heat load from the servers and output is the airflow out from the datacenter. In the model, the temperature out was controlled to 35°C. A correlation was then created from the results and used in the greenhouse dimensioning.

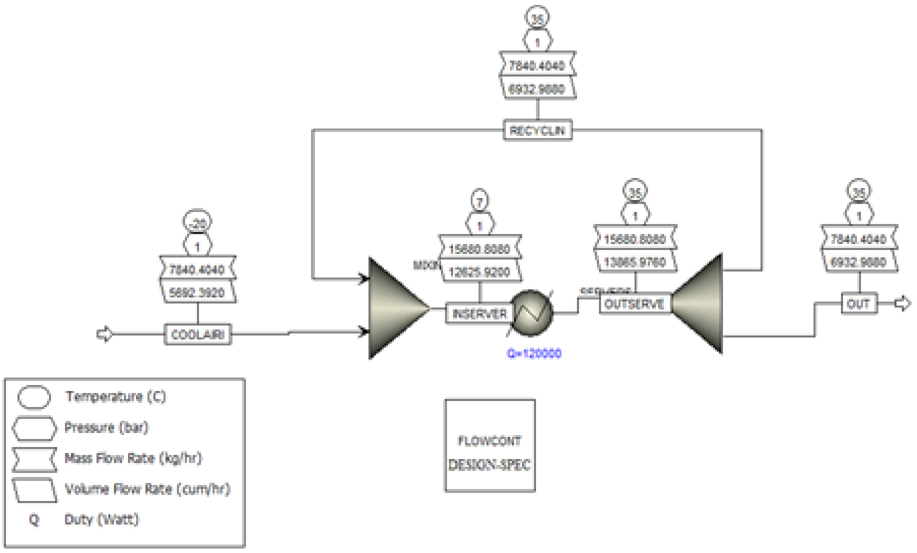

Figure 3: Process model of the datacenter used to determine mass flow of air at a specified temperature for different outdoor temperatures.

The heat transfer model presented in Figure 4 is consisting of the airflow from the datacenter that are heat exchanged with water. The heated water is then transported in a pipe to the greenhouse where used as heat. After the greenhouse, the water is then recirculated in pipe back to the heat exchanger where it is reheated. The inputs to the model is airflow from the datacenter, distance between datacenter and greenhouse and the outdoor temperature, the output is the available heat at the greenhouse. The results from the model was then converted to a correlation that are used for the greenhouse dimensioning.

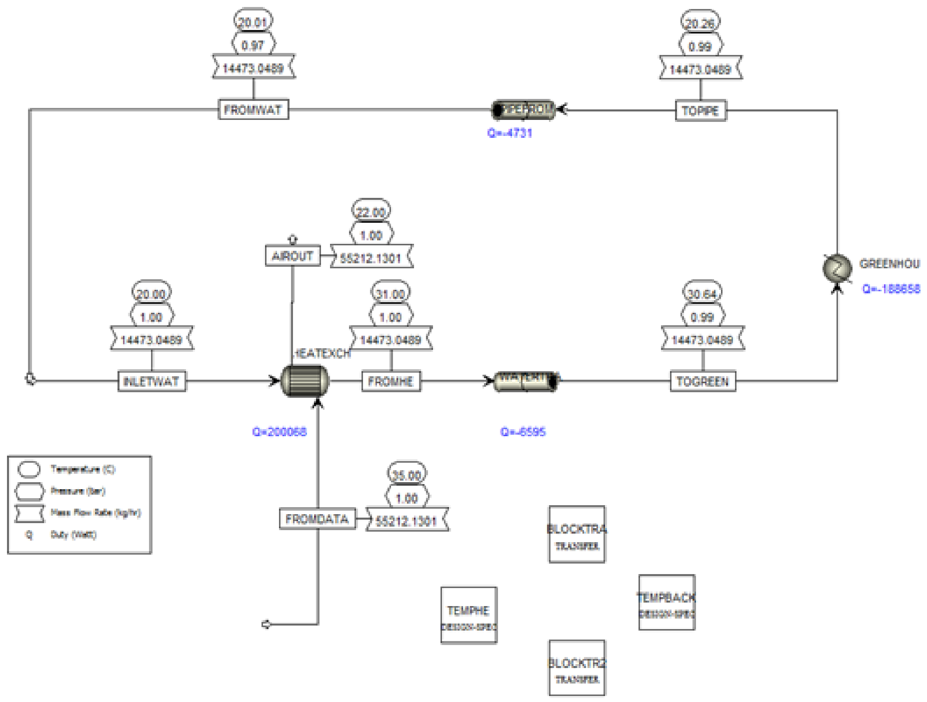

Figure 4: Process model of the heat transfer solution.

For the greenhouse dimensioning an excel spreadsheet was developed that considers the outdoor temperature based on data from the Swedish Meteorological and Hydrological Institute (SMHI), datacenter size, greenhouse building envelope and distance between datacenter and greenhouse. In this excel spreadsheet the correlation from the process model was implemented.

4. RESULTS

4.1. General framework

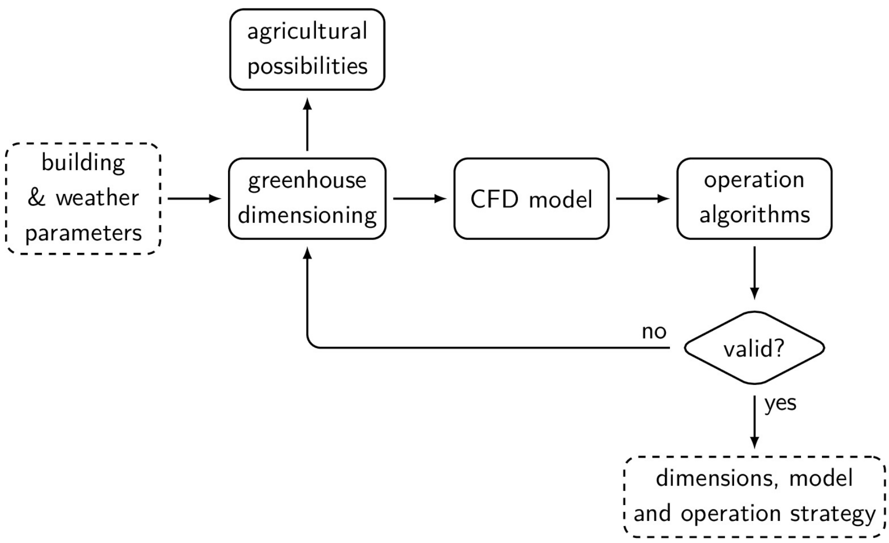

Figure 5. Proposed modelling methodology.

The methodology proposed in this paper, graphically summarized in the chart in Figure 5, is the following: starting from the requirements of having preliminary information on: the structural parameters on the datacenter (such as expected maximal power usage); the properties of the greenhouse (such as u-values of the walls); the requirements of the minimal and maximal temperature within the greenhouse; statistics on the weather conditions for the location (thus not only, e.g., daily average temperatures, but also traces of actual past evolutions so to be able to assess the extent of variations from nominal average values); and a CFD model of the datacenter.

The first step is then to perform an initial greenhouse dimensioning, considering the average weather conditions and using the first principles modeling and computations described in Section 3.3. Following this dimensioning, the designer should then: i) generate a CFD model of the greenhouse, ii) obtain the control-oriented one by performing system identification on the systems using the CFD models as virtual plants as explained in Section 2.3; iii) implement predictive control systems on top of the so-identified model; iv) eventually embed these controllers into the CFD models above. In this way, the designer obtains a complete CFD simulator of the system in closed-loop (i.e., something that simulates how the system should behave not only when the weather conditions are the nominal, but also when these change).

With this closed-loop simulator the designer can then understand if the data center - greenhouse system designed up to now can sustain the typical variations in the weather conditions. The designer can indeed understand through simulations if this system can reject weather disturbances by opportunely acting on the indoor-conditioning subsystem, and guarantee that the temperature of the greenhouse above the required one for all the colder-than-average situations collected in the traces mentioned in the first step of the methodology.

The proposed methodology then works as follows: if the overall system can reject the weather disturbances as intended above, then it is meaningful to try to consider what would happen with a bigger greenhouse (i.e., change the design of the greenhouse and then re-perform the steps above). If instead the disturbances are not rejected, then it is necessary to consider a smaller greenhouse. Our proposal is then to iterate the steps above up to the moment that one finds a "big-just-enough" greenhouse.

4.2. Example

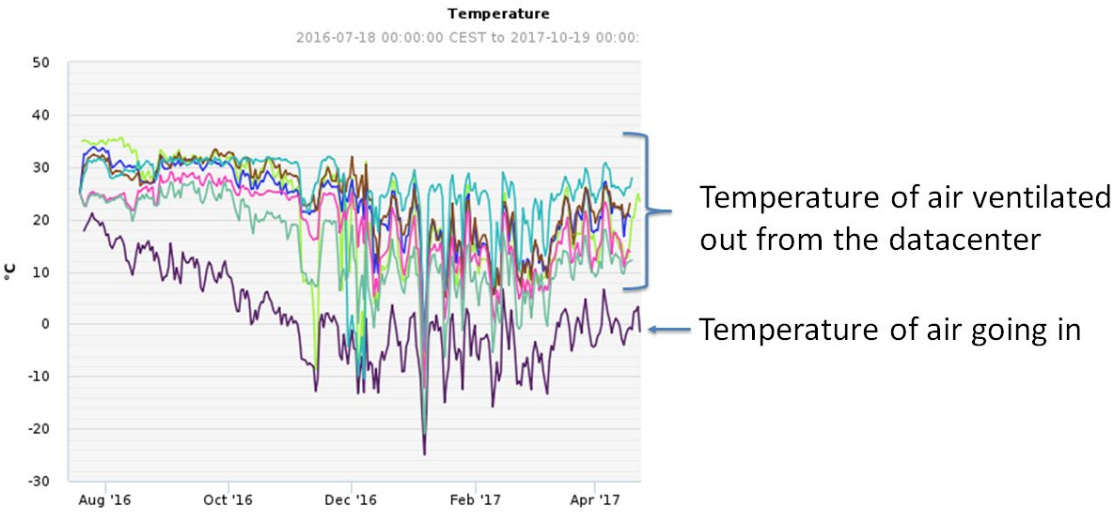

Figure 6. Measured temperature of the air ventilated out and air going into the Hydro66 datacenter.

In Figure 6 the measured temperature is presented. The temperature of the air going out is from below zero up to 35°C. When the outgoing air is below zero the ventilation fans are shut off.

In the following example, the datacenter located in Boden, not far from the Arctic circle, has a load of 1 MW and the greenhouse has a width of 12.5 m and a height of 4 m with double pane glass for the green house. In Figure 7 the results for the length of the greenhouse dependent of outdoor temperature (left) and the date (right) is presented. For a low temperature under -10 °C the data center can support a greenhouse that is 50 m long and when the temperature goes the down to -30 °C it can only support a length of 17 m. Over the year, during the winter, only a small greenhouse can be heated from the datacenter but during the summer a large greenhouse of length 300-400 m could be heated.

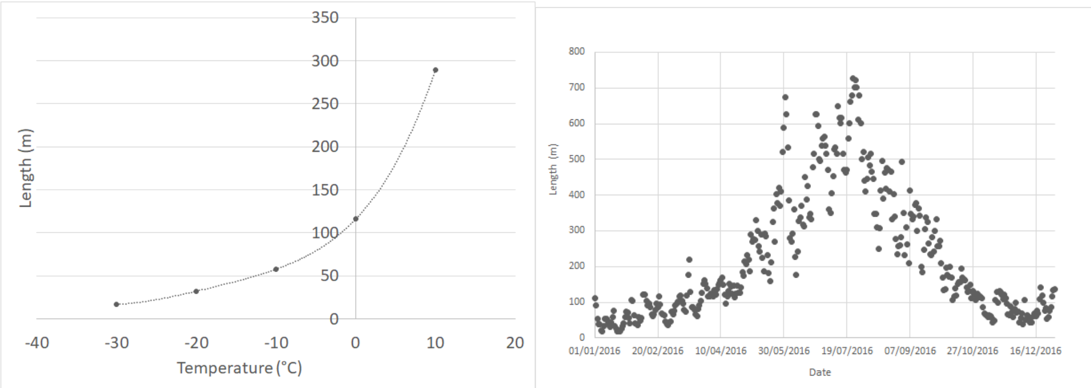

Figure 7: Example of results from the greenhouse dimensioning for a datacenter of 1 MW located in Boden, Left: Length dependent of outdoor temperature, Right: Length dependent on date.

In Figure 8 the airflow inside a suggested greenhouse is evaluated. Here it is possible to evaluate fan solutions and other ventilation related parameters.

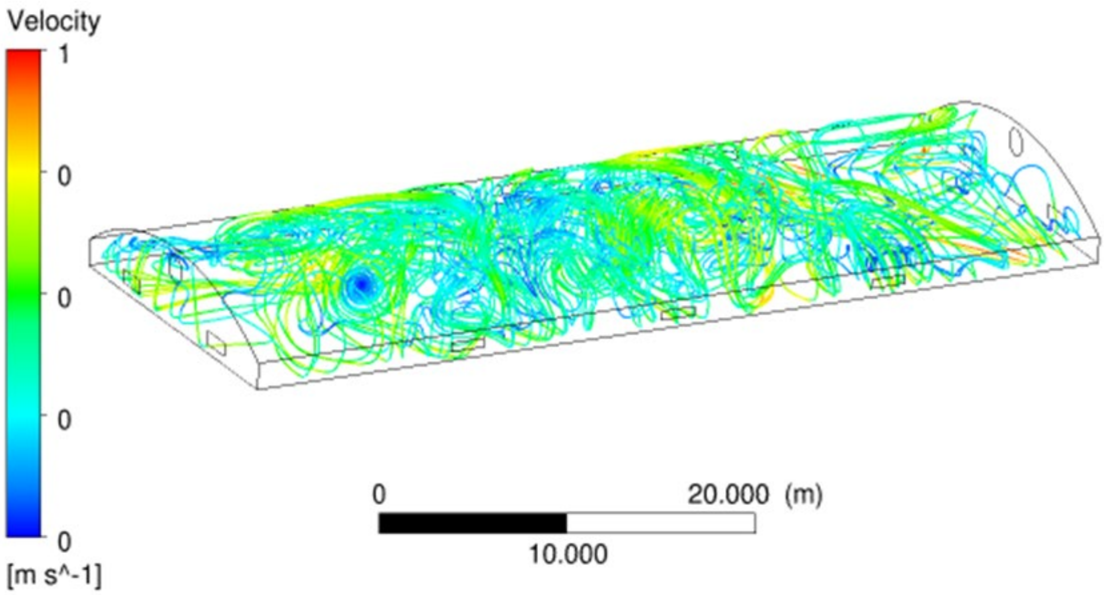

Figure 8. Computational fluid dynamics model of a suggested greenhouse.

5. DISCUSSION

During the winter only a small greenhouse can be heated from the datacenter. Therefore, if the greenhouse should be used during the coldest part of the year additional heating will be needed which for example could be district heating, pellets burner or biogas. Another option is only to use the heat to extend the growing season and not use it during the coldest months. The process modeling part have some uncertainties that needs to be addressed before the heat transfer solutions is implemented in a real system. The first one is the heat exchanger sizing after the data center. Since it's several air outlets from the datacenter one options is to have a heat exchanger connected to each outlets but this will probably end up in a very costly solution while the other options is the gather the airflows together which will be a practical problem for an existing datacenter since it is not designed according to that. The other uncertainties it how much heat that can be used in the greenhouse since currently greenhouses are not designed to use low temperature heating system and therefore more work are needed in this area.

The waste heat from the datacenter can be considered for cultivations of variable crops including vegetables, ornamental plants, berries, spices and edible mushrooms, however exact design for dedicated species is beyond this current study. The fact that the heat exiting from the datacenter is below the 35°C suggests that the target crops shall be reasonably among those species having low heat requirement for the growth. For example, the optimal air temperature during the cultivation is about 15 - 20 °C for spices (such as parsley, grass onion, basil, lemon balm etc.) and ornamental plants (such as pence, primula, geranium, etc.), and 10 - 18°C for shiitake and oyster mushrooms [9]. The exact design shall also incorporate with other inhouse climate variables such as lighting, CO_2 and relative air humidity. It is worth addressing that many edible mushrooms are growing on forest or crop residues and have a low demand of lighting (500 - 2000 lux, depending on strains and growth stages) as well as less requirements for fertilizers and pesticides. Cultivation of edible mushrooms has drawn more global attentions in recent years, because edible mushrooms are protein rich [10] and contain components good for human health [11]. Edible mushrooms have also been suggested as one of potentially alternative to substitute meat since meat production and associated transportation have caused considerable greenhouse gas emissions [12].

It is understood that a use of the waste heat from datacenters, i.e. a type of secondary energy source, for greenhouse cultivation shall contribute to a low CO_2 footprint, in general or in respect of the users. However, any implementation regarding to such a move have to consider an innovative and system solution for an optimized energy balance and cost efficiency. It could be explorable in future work, for example, an integrated cultivation of ornamental plants/vegetables that demands for light and CO_2 input, and edible mushrooms that prefer to darkness and emit CO_2. The development of a digital system enabling control and monitoring of the entire heat flow and mechanical devices from datacenter to crop growth chamber will be important and make a smart industrial integration possible.

6. CONCLUSIONS

A modelling approach using process modelling, computational fluid dynamics and control-oriented models to assess the use of waste heat from datacenter in greenhouses, have been presented. Using the models, we have shown that it is possible to run greenhouses on waste heat in the north of Sweden but you may need additional heat sources. The modelling approach could benefit from validation on real greenhouses and energy transfer solutions.

7. ACKNOWLEDGMENT

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8. REFERENCES

[1]. Fit4Green (2017), http://cordis.europa.eu/project/rcn/93739_en.html Accessed 20171018
[2]. GAMES (2017), http://www.green-datacenters.eu/ Accessed 20171018
[3]. Ebrahimi K., Jones G.F. and Fleischer A.S. (2014) "A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities". *Renewable and Sustainable Energy Reviews* 31: 622-638.
[4]. Parker T. and Kiessling A. (2016) "Low-grade heat recycling for system synergies between waste heat and food production, a case study at the European Spallation Source", *Energy Science & Engineering*, vol. 4(2), pp. 153-165
[5]. Ward, E.M., Goedke, M.L., Brenner, P. and Go, D.B, (2012) "A simplified thermodynamic model for waste heat utilization from a containerized data center experimental platform", *Proceedings from the 13th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electric Systems (iTherm)*. pp 521-529, May 30 - June 1, San Diego.
[6]. Nikoo, B.M., Mahinpey, N., "Simulation of biomass gasification in fluidized bed reactor using ASPEN PLUS", *Biomass and Bioenergy*, Vol. 32(12), 2008, pp. 1245-1254
[7]. G. De la Torre-Gea1, G. M. Soto-Zarazúa, I. López-Crúz, I. Torres-Pacheco and E. Rico-García, "Computational fluid dynamics in greenhouses: A review", African Journal of Biotechnology, vol. 10(77), pp. 17651-17662, Dec. 2011.
[8]. B. Francesco, A. Bemporad, and M. Morari. *"Predictive control for linear and hybrid systems"*. Cambridge University Press, 2017.
[9]. Nilsson U. and Nimmermark S. (2012) "Use of waste heat for greenhouse production", Swedish University of Agricultural Science Department of Rural Buildings, Report 2012.
[10]. Croan S.C. (2004) "Conversion of conifer wastes into edible and medicinal mushrooms". *Forest Prod. J*. Vol. 54, pp. 68-76.
[11]. Enman J, Rova U, Berglund KA. 2007. Quantification of the bioactive compound eritadenine in selected strains of shiitake mushroom (*Lentinus edodes*). *J agric food chem* Vol 55, pp. 1177-1180.
[12]. FAO 2013. Climate-Smart Agriculture Sourcebook. United Nation Food and Agricultural Organization.