cal greenhouse researchers [5] have estimated the heating requirements for a greenhouse using LED-based lighting as 300–450 kWh/m^2. Their energy estimates a growing period from February to October. Assuming equal sunlight and that heating is required for only a fifth of May and September, half of June, and none of July or August, this would translate to an average power draw of 68–102 W/m^2. Note that as the sun does shine even during the colder months, the heating load fluctuates over the average during the night, and vice versa during the day. This causes the above calculation to underestimate the worst case for the heating. However, as our prototype's heat signature is currently 362–383 W/m^2 (Sect. 3.3), the servers can easily overprovide the requirements even during the colder months. This adds some confidence that harvesting heat remains feasible for larger greenhouses with relatively fewer servers required.

If we would concentrate only on the most successful chili peppers in our greenhouse, we could extend the yield from roughly 500 to over 1830 chili peppers in our 9.4 m^2 greenhouse. In contrast to our power draw of 3.4–3.6 kW, the local CS Dept.'s data center consumes roughly 80–110 kW during normal and peak operations [6]. Currently all of the heat is wasted, as it is radiated into the air by a cooling tower located in the vicinity of the greenhouse.

If we could harvest a conservative 80% of the Exactum DC's waste heat, we could heat up a similarly constructed greenhouse of ca. 177–230 m^2. Thus, using the available heat we could grow roughly 34,500–44,800 chili peppers. During summer 2012, the market price for *Capsicum annuum* 'Aji Cristal' produced in Finland was 92.50 euro per kg, or roughly an euro per chili pepper.

Finally, as the heat produced is pretty constant, the exhaust must in due time be vented from the greenhouse. After that, the heat could still be reused in a district heating network, to heat local buildings or water reservoirs, or melt snow in the harshest climates.

6. CONCLUSION AND FUTURE WORK

In this article, we have demonstrated the feasibility of harvesting server heat and reusing it in a greenhouse environment. We have successfully extended the growing season of the plants by mimicking the synthetic conditions of larger greenhouse environments. Our prototype is a proof-of-concept installation combining both the urban gardening concept and free air cooling.

In future work, we will further describe our experiences by focusing on the most well-adapted plants, detail the requirements for sunlight, and explain the feasibility of biological pest deterrents. Additional LED lighting should be evaluated as a possibility for the winter season. Starting from 2013, we have plans to extend our co-operation with agricultural researchers and revisit the possibilities for symbiosis of large-scale data centers and greenhouses.

While a lightweight construction similar to ours was feasible on top of the Exactum building, much more power-hungry DC installations exist. These facilities are typically located outside urban environments, can require hundreds of kilowatts of power, and require up to thousands of square meters of space. Interestingly, all of these attributes apply to large-scale greenhouses as well. Thus, very large-scale DC installations could be very successful companions to very large-scale greenhouses in rural environments.

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8. REFERENCES

[1] P. Brenner, D. Thain, and D. Latimer. Grid Heating Clusters: Transforming Cooling Constraints into Thermal Benefits, 2009.

[2] K. Church, A. Greenberg, and J. Hamilton. On Delivering Embarrassingly Distributed Cloud Services. In *HotNets-VII*, pages 1–6, Calgary, Alberta, Canada, 2008. ACM.

[3] K. Jokinen, L. Särkkä, T. Kaukoranta, A. Koivisto, J. Näkkilä, and R. Tahvonen. Energiahaasteet ja -ratkaisut kasvihuonetuotannossa Avoin, suljettu vai puolisuljettu? *Puutarha&kauppa*, (25-26):30–31, 2010.

[4] T. Kaukoranta, J. Näkkilä, L. Särkkä, and K. Jokinen. Energian käytön ja kasvihuonekaasujen vähentämisen potentiaali kasvihuonetuotannossa. In *Maataloustieteen päivät*, pages 5–8, 2012.

[5] T. Kaukoranta, L. Särkkä, J. Näkkilä, A. Koivisto, and K. Jokinen. Kehittyvä teknologia vähentää kasvihuoneen energiankulutusta. *Maaseudun tiede*, (2), 2011.

[6] M. Pervilä and J. Kangasharju. Cold air containment. In *Proceedings of the 2nd ACM SIGCOMM workshop on Green networking - GreenNets '11*, pages 7–12, New York, New York, USA, 2011. ACM Press.

[7] M. Pervilä and J. Kangasharju. Running Servers around Zero Degrees. *Computer Communication Review*, 41(1):96–101, 2011.

[8] M. Pervilä, M. Rantanen, and J. Kangasharju. Implementation and Evaluation of a Wired Data Center Sensor Network. In *Proceedings of the 1st International Workshop on Energy-Efficient Data Centres (E2DC 2012)*, 2012.