Center for Energy and innovative Technologies

The First Step for Implementing a Stochastic based Energy Management System at Campus Pinkafeld

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ABSTRACT: At Campus Pinkafeld the average demand for electricity in the last five years was 199 MWh_{el}. The supplier Burgenländische Elektrizitätswirtschafts-Aktiengesellschaft (BEWAG) states that it supplies only green electricity in its service area and average CO_2 emissions are 0.0 kg/kWh_{el}. The average demand for thermal heat for the district heating system operated by KELAG in recent years was 219 MWh_{th}. The heat for the district heating network comes from a maize-fired biomass power plant. Biomass power plants are generally considered to be CO_2-neutral. Analyzing the potential of reducing marginal CO_2 emissions by Distributed Energy Resources (DER) is the major objective of this paper and the EU-funded project "Energy Efficiency and Risk Management in Public Buildings" (EnRiMa). The aim of EnRiMa is to develop a decision support system (DSS) to enable operators to manage energy flows in public buildings, delivering a holistic solution for meeting the energy needs in a more efficient, less costly, and less CO_2 intensive manner subject to comfort tolerances and long-term risk preferences. To get first deterministic optimization results for different DER options the exiting web version of the Distributed Energy Resources Customer Adoption Model (DER-CAM) is used. The optimization runs using DER-CAM show that a switch to a natural-gas-fired CHP plant can result in financial advantages. Compared to the marginal power plant used to meet the avoidable peak power demand, a switch to local energy generation with combined heat and power (CHP) is certainly of interest. It can be assumed that BEWAG must purchase some of its peak power from other energy suppliers. Such peak power can be supplied from gas-fired plants with marginal CO_2 emissions of approx. 0.44 kg/kWh_{el}. These emissions could be reduced by local CHP systems. With the use of stochastic weather information or other stochastic parameters the investment / planning as well as operational activity will be calculated within EnRiMa and will create a stochastic optimization platform not available in DER-CAM.

1. INTRODUCTION

On average, over one-third of national energy demand is required for building heating and other electrical systems within households and services. According to energy statistics from the European Union (EU), consumption within buildings is 40% with rising trend. Reduction of energy demand and increased use of renewable energy sources are the main activities for decreasing Europe's energy dependency and its greenhouse gas emissions. Energy consumption for residential and commercial buildings grew from 20,809 to 32,532 TWh/a between 1980 and 2010 – an increase of 56% in 30 years. Up to 2030, a further increase of 21% is expected. A rise of 6,741 to 39,273 TWh per year is projected up to 2030 – an average increase of 337 TWh per year. It is assumed that the energy saving potential in the residential sector is over 60%. This would lead to an energy consumption of around 13,000 TWh (EU, 2010a).

The target of the energy and/or CO_2 minimization is to provide a set of possibilities how the Campus Pinkafeld can operate their facilities. Based on stochastic weather forecasts the **operational module** will be able to define the optimal strategy for the day ahead operation. Considering stochastic parameters as e. g. fluctuating prices in energy prices and unstable building occupancies by the students, the **strategic module** is generating a set of possibilities how the management can choose their focus within the facility management. The management can decide if they are willing to minimize CO_2, minimize the energy costs, or if they are looking for a multi-objective-minimization goal where CO_2 and energy costs are considered in parallel. However, at this point this stochastic EnRiMa optimization is not completed, and therefore, the deterministic DER-CAModel from Lawrence Berkeley National Laboratory (LBNL) has been used to assess major strategies at Pinkafeld.

Siemens facility management software DESIGO™ is used at Campus Pinkafeld. The required heating, cooling and electricity loads for the optimization are not recorded with the required quality. Existing software solutions, such as TRNSYS (TRNSYS, 2011) and EnerCalC (Lichtmeß, 2010) are either too complex or calculate only monthly and yearly energy demands. Therefore, LoadCalc, a simple building model was created to allow building owners with no sufficient or without an energy or facility management system to optimize their energy requirements. On the basis of DIN 18599 (draft) and VDI 6020, it is possible to create a simplified building model that is sufficiently accurate to meet the requirements of the EU-funded project "Energy Efficiency and Risk Management in Public Buildings" (EnRiMa) (www.enrima-project.eu, 2011). One of EnRiMa's test sites for the new stochastic optimization is the University of Applied Science of Burgenland, Campus Pinkafeld. The output of LoadCalc are hourly load curves for electricity, heating and cooling and used within DER-CAM and in the future in the stochastic EnRiMa optimization.

2. DER SITUATION

This analysis considers the main building of the Pinkafeld Campus only. The laboratory is not part of this research. Pinkafeld Campus is connected to Pinkafeld's district heating system which is operated by KELAG Wärme GmbH. Campus Pinkafeld consumed between 187 and 246 MWh_{th} in the last 5 years. The rated peak heat capacity of the heat exchanger and, therefore, of the district heating system is 162.8 kW_{th}. About 70.7 kW_{th} is used to heat the air in the air-conditioning system. Cooling, dehumidification and preheating take place within the air ventilation system which has a capacity of about 13,000 m^3/h. A cooling capacity of 47.9 kW_{th} is available. The average heat recovery by the air ventilation system is given by 71%. A 1.28 kW_p PV system is installed onsite. The requested electricity demand of between 190 and 217 MWh_{el} is provided by Burgenländische Elektrizitätswirtschafts-Aktiengesellschaft (BEWAG) (FHS Burgenland, 2011).

3. BUILDING MODEL

The existing facility management system at Pinkafeld Campus does not deliver the required information in the necessary level of details. Existing software solutions, such as TRNSYS and EnerCalC are either too complex or calculate only monthly and yearly energy demands. Therefore, a building simulation model was created: LoadCalc. On the basis of DIN 18599 (draft) and VDI 6020, it is possible to create a simplified building model that is sufficiently accurate to meet the requirements of the DER-CAM optimization tool and the project EnRiMa. The goal of LoadCalc is to obtain hourly load data for cooling, heating, and electricity, which can be used in optimization tools.

3.1 BRIEF MODEL DESCRIPTION

To perform a correct simulation of the performance of the building, it is very important to use real and available data as much as possible. The end-use demand of heating, cooling and electricity is calculated within our LoadCalc building model.

The following topics are covered by the buildings model in this work: weather (temperature, humidity and wind), heat transfer and heat transfer coefficient, external loads (solar radiation), internal loads (people, working machines), natural infiltration, air ventilation systems (without humidity constraints) and business and non-business hours.

To keep the simulation as simple as possible, the following assumptions are considered: room air temperature is constant within the entire operative zone; calculations are made for a stationary situation; building is regarded as a cuboid or cube and heat flow is normal to the given surfaces.

The following simplifications are considered: air quality is not part of the model; daylight calculation and visual comfort are not considered; air flow (direction and speed) within the building is not considered; air humidity is not considered (neither transport through walls nor the humidity released by people); point thermal transmittance is not considered and hot water consumption is not considered.

3.2 MODEL DETAILS

Figure 3-1 shows the situation with regard to the building performance. This paper considers all of these components in order to derive appropriate results.

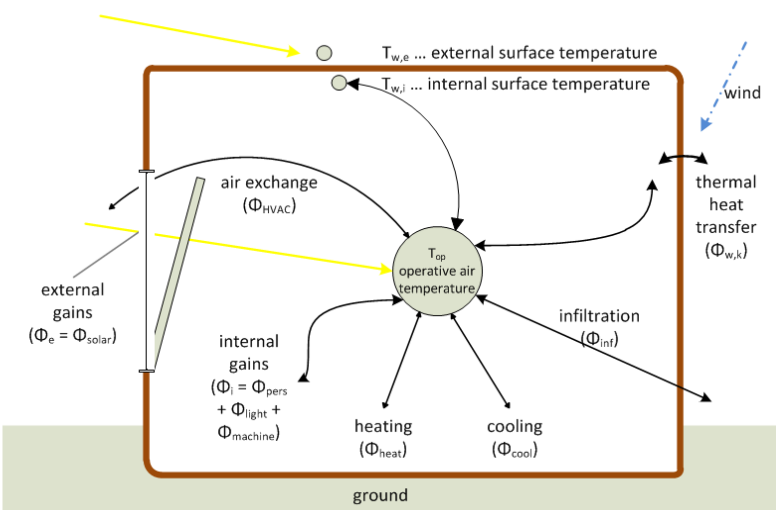


Figure 3-1: Energy flow paths within buildings (CET)

The following enhancements according to DIN 18599 (draft) and VDI 6020 are considered:

- Load calculation on an hourly basis
- Internal loads are considered (Sundays and public holidays are considered)
- Solar radiation is calculated in detail (varying solar constant)
- Solar radiation is calculated for each surface and orientation
- External heat transfer coefficient is variable (depending on wind speed)

- On the external side of the surface, the solar air temperature is considered for heat transfer calculations; and
- Ground temperature is variable.

3.3 MODEL VALIDATION

As the quality of data from Campus Pinkafeld does not result in continuous data for an entire year, the building model validation on an hourly basis is not possible.

However, one item that can be checked is the monthly hot water demand delivered by the district heating system. For this check, data are available for 2009 and 2010. The consumed MWh_{th} from the district heating system is equal with a projected MWh_{th} from LoadCalc, both are end-use energy. In 2009 the heating demand was 223 MWh_{th}, in 2010 it was 207 MWh_{th}. Within the average year the heating demand is 231 MWh_{th}. The observed heating demand varies between -3.4 and -10.4% around the values of the average year (on a yearly base). The main reason is that LoadCalc is a static simulation program. So no thermal heat storage or the building shell is considered. For more details about the building and recent situation at Pinkafeld Campus see Groissböck et. al, 2011.

4. OPTIMIZATION SOFTWARE

Since EnRiMa has started in November 2010, no stochastic optimization software is available at the moment. Therefore, another optimization tool is used for this paper to get first results in optimizing the energy situation at the Pinkafeld Campus. In this paper the *deterministic* Distributed Energy Resources Customer Adoption Model (DER-CAM) optimization tool is used. DER-CAM has been created by Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), California, U.S.A. See also DER-CAM (2011).

This section describes Distributed Energy Resources Customer Adoption Model (DER-CAM) is taken from Siddiqui et. al (2005), Stadler et. al (2010) and Stadler et. al (2011).

DER-CAM is a techno- economic model of distributed energy resources (DER) adoption implemented within the optimization software General Algebraic Modeling System (GAMS) as a mixed-integer linear program (MILP) created and further developed by Ernest Orlando Lawrence Berkeley National Laboratory (LBNL). The objective of DER-CAM is to minimize the cost of supplying energy services (building heating, cooling, electricity, natural gas). Therefore, it optimizes the installation and operation of the available equipment (e. g. distributed generation (DG), combined heat and power (CHP), thermal driven cooling, or storage). The optimization is focused on techno-economic aspects and environmental issues (e. g. CO_2 emissions) can be considered.

The DER-CAM model is based on some assumptions:

- Decisions are based on direct economic criteria only (= reduction of customer's costs)
- Degradation of output or efficiency during the lifetime of the devices is not considered
- Start-up and other ramping constraints are not included
- Stochastic resolution is not possible.

Figure 4-1 shows a high-level schematic of the energy flows modeled by DER-CAM. The energy inputs are solar radiation, electricity and natural gas prices as well as loads. Conversion losses are also considered. Apart from the goal of minimizing the annual costs, constraints are also considered in the optimization process. Constraints such as meeting the energy demand at each time step and thermodynamic laws (energy conversion and transfer) are considered as well.

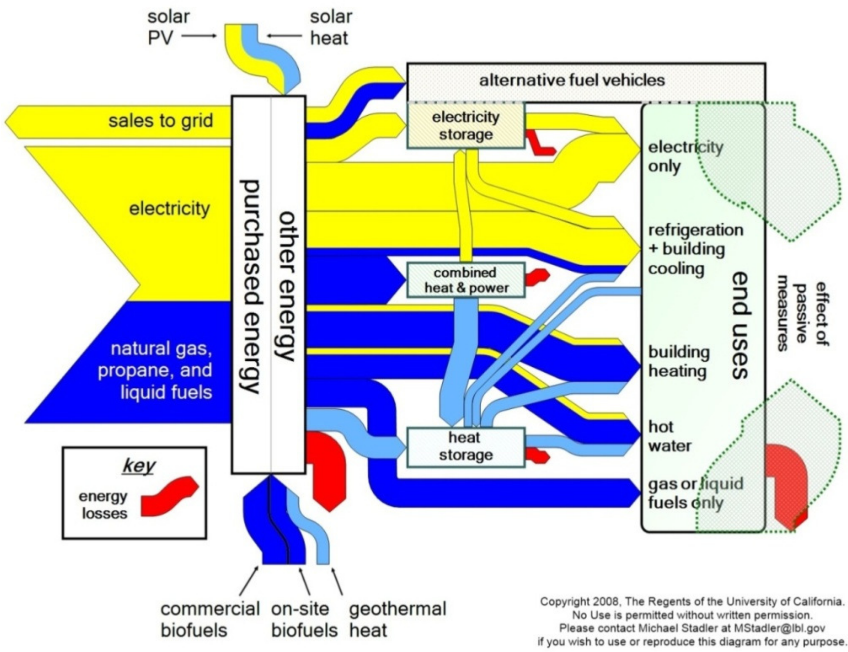


Figure 4-1: Schematic of energy flows in DER-CAM (Stadler et. al, 2011)

To operate DER-CAM accurately, some inputs are required for defining the customer's behavior:

- End-use load profiles (heating, cooling and electricity demand) (three daily profiles are required for each month: weekday, peak day and weekend day). These load profiles are provided by the LoadCalc model designed within this work.
- Tariffs (electricity, natural gas and other relevant price data)
- Characteristics of available technologies (capital costs, operation and maintenance (O&M) costs and fuel costs) and
- Interest rate on investment.

Major outputs of DER-CAM's optimization process are:

- Capacity of technology to be installed
- Optimized hourly schedule of the installed technologies
- Total cost of energy supply (electricity, heat and cooling)
- Total fuel consumption and
- Total CO_2 emissions.

5. OPTIMIZATION AT CAMPUS PINKAFELD

DER-CAM is used to examine which kind of DER technologies might be of interest for Campus Pinkafeld.

This chapter explains the recent DER situation at Campus Pinkafeld including the CO_2 emissions. This is followed by a description of the transition from district heating to a gas-fired boiler system. The following three scenarios are examined:

- Scenario (1): switch to NG-fired boiler

- Scenario (2): minimize costs
- Scenario (3): minimize CO_2 emissions

5.1 CO_2 EMISSIONIS

BEWAG specifies its own CO_2 emissions with 0.0 kg/kWh_{el}. Austrian average emissions are 0.195 kg/kWh_{el}. As the district heating system in Pinkafeld runs on maize from suppliers around Pinkafeld, CO_2 emissions of 0.03 kg/kWh_{th} are assumed. An average emission value is valid for the entire supply area, but questionable for one single building since DER reduces the marginal CO_2 emissions. In other words, DER at a single building only influences the marginal power plant used to balance supply and demand. Of course, defining this marginal power plant and its emissions is a difficult task since the marginal power plant changes every hour. The analysis of marginal power plants is not part of this paper.

Table 5-1: CO_2 emissions in 2009 at Campus Pinkafeld (CET)

	Demand	Estimated *average* CO_2 emissions		*Marginal* CO_2 emissions	
	MWh	kg/kWh	kg/year	kg/kWh	kg/year
Electricity	217.1	0.195	42,328.65	0.440	95,510.80
Heating	245.8	0.030	7,374.00	0.030	7,374.00
Total	462.9	0.107	49,702.65	0.222	102,884.80

Marginal CO_2 emissions for electricity are assumed with 0.440 kg/kWh_{el} as this might be the emission from a natural gas fired peak plant unit.

Table 5 1 shows the annual emissions of CO_2 at Campus Pinkafeld. No transport or conversion losses, and therefore, no additional CO_2 emissions are considered in these calculations. The estimated average CO_2 emissions for 2009 are 49.7 t/a. The marginal CO_2 emissions are 102.9 t/a. This shows the difficulty of choosing the correct value of CO_2 emissions.

5.2 DER-CAM INPUTS

An interest rate of 6% is assumed. A maximum payback period of 12 years is assumed for possible DER investments. 90% of the roof is assumed to be used for solar technologies which are 1,880 m².

The cost data are expressed in 2008 US$ and are estimates for 2020. An exchange rate of €1=US$1.44 is used in this paper (www.xe.com, 2011).

At present, no natural gas is used for heating or cooling at Campus Pinkafeld.

Table 5-2 and Table 5-3 show the investment parameters within the technology data for the optimization runs (with and without heat recovery). Alpha (in Table 5-2) represents the amount of recoverable heat (kW_{th}) from 1 kW_{el} produced.

The following technology abbreviations are used within DER-CAM: ICE: internal combustion engine; FC: fuel cell; HX: heat exchanger; MT: micro turbine; PV: Photovoltaic; ST: solar thermal; BS: battery system; HS: Heat storage.

Table 5-2: DER-CAM investment parameters, with heat recovery (HX) (Stadler, 2010)

Parameter	Capacity [kW]	Capital costs [US$/kW]	Variable maintenance costs [US$/kWh]	Lifetime [years]	Electric efficiency [%, HHV]	Alpha [-]
ICE-HX	60	3,580.00	0.02	20	29.0	1.73
MT-HX	60	2,377.30	0.02	10	25.0	1.80
FC-HX	60	2,770.10	0.02	10	36.0	1.00

Table 5-3: DER-CAM investment parameters, without heat recovery (Stadler, 2010)

Name	Capacity [kW]	Capital costs [US$/kW] unless specified differently	Variable maintenance cost [US$/kWh] unless specified differently	Lifetime [years]	Electric efficiency [%, HHV]
ICE	60	2,721	0.02	20	29.0
MT	60	2,116	0.02	10	25.0
FC	60	2,382	0.03	10	36.0
PV	any size	3,237	0.25 US$/kW	20	na
ST	any size	500	0.15	15	na
BS	any size	193 US$/kWh	0.00	5	na
HS	any size	100 US$/kWh	0.00	17	na

Table 5-4 shows the energy storage options within the simulation settings for the optimization runs.

Table 5-4: DER-CAM energy storage parameters (Stadler, 2010)

Parameter	Electrical	Thermal	Description
Charging efficiency	0.90	0.90	Portion of energy input to storage that is useful
Discharging efficiency	1.00	1.00	Portion of energy output from storage that is useful
Decay	0.001	0.01	Portion of state of charge lost per hour
Maximum charge rate	0.10	0.25	Maximum portion of rated capacity that can be added to storage in an hour
Maximum discharge rate	0.25	0.25	Maximum portion of rated capacity that can be withdrawn from storage in an hour
Minimum state of charge	0.30	0.00	Minimum state of charge as portion of the rated capacity

5.3 DER-CAM OPTIMIZATIONS

Required information about the electricity, heating and cooling load is provided by LoadCalc and channeled into DER-CAM.

The do-nothing run is to calibrate DER-CAM to the situation at Campus Pinkafeld. No change to the recent situation is considered. The switch to NG-boiler run shows the results if a natural gas-fired boiler instead of district heating is considered.

The min cost run considers the current situation at Campus Pinkafeld and finds the most economical solution for the energy supply by also considering DER as an additional option and using district heating when necessary. Annual costs decrease by 22%. The yearly consumption of natural gas is estimated with 722 MWh_{th}. About 65 MWh_{th} is still consumed from the district heating system. 99.8% of the electricity demand is met by on-site generated electricity. Marginal CO_2 emissions rise by about 18%. This increase is mainly due to the limited usage of district heating.

Table 5-5: Results of the Optimization runs at Campus Pinkafeld (CET)

		Do nothing	Switch to NG fired boiler	Min. costs	Min. CO_2
Size of PV	m²	-	-	-	1195
Size of solar thermal	m²	-	-	-	205
Battery capacity	kWh_{el}	-	-	-	314
Heat storage	kWh_{th}	-	-	257	339
NG fired-boiler	kW_{th}	-	160	-	-
DG capacity	kW_{el}	-	-	60	-
Natural gas purchase for DER	MWh_{th}/a	-	287	722	-
Thermal heat purchased (district heating)	MWh_{th}/a	223	-	65	213
Electricity generated on-site	MWh_{el}/a	-	-	199	184
Electricity purchase (utility)	MWh_{el}/a	199	199	-	15

		Do nothing	Switch to NG fired boiler	Min. costs	Min. CO_2
Annual energy costs	%	100	110	78	150
Annual marginal CO_2 emissions	t/a	103	136	121	13
Marginal CO_2 savings	%	-	-32	-18	87

The min. CO_2 case considers the current situation at Campus Pinkafeld and finds the most environmental friendly solution for the energy supply. DER is considered as additional option. However, the objective is to minimize the marginal CO_2 emissions with a cost constraint. Therefore, an energy cost increase cap of 50% is introduced to limit the negative cost impact on Pinkafeld.

The yearly consumption of natural gas is estimated with 213 MWh_{th}. The purchased electricity is calculated with 15 MWh_{el}. The electricity demand is met by 92% on-site generated electricity. Marginal CO_2 emissions decrease by 87%.

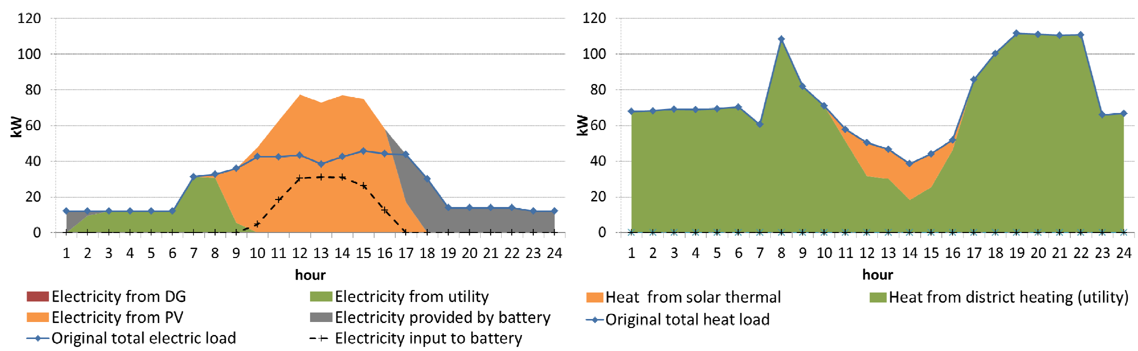


Figure 5-1: Minimize CO_2 emissions: electricity and heat pattern for a January peak day (electricity, heating) from the Campus Pinkafeld optimization (DER-CAM, CET)

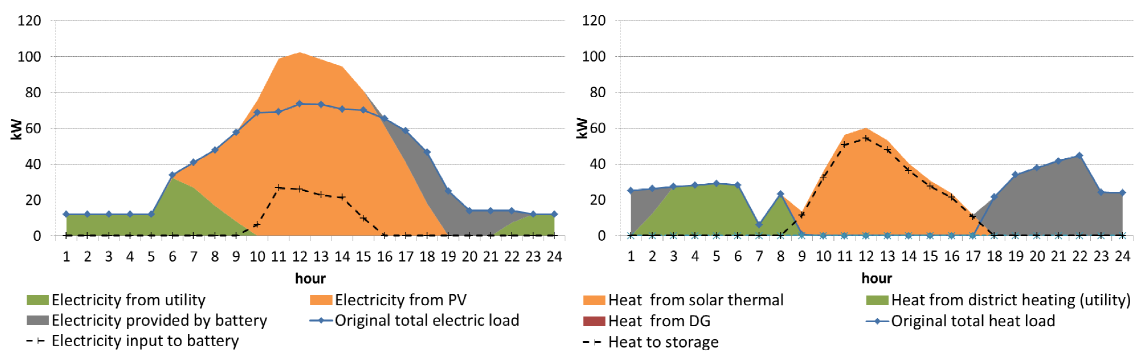


Figure 5-2: Minimize CO_2 emissions: electricity and heat pattern for a September peak day (electricity, heating) from the Campus Pinkafeld optimization (DER-CAM, CET)

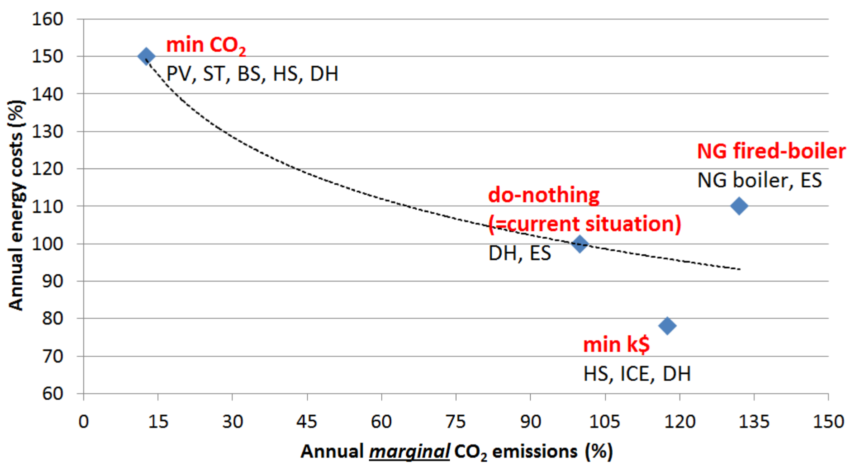
Figure 5-1 and Figure 5-2 show the electricity and heat pattern for a January and September peak day, respectively. The electricity from the PV system is stored in batteries and is used at times when there is no sunshine (morning and evening hours). Consequently, less electricity is required from the utility. The heating load is provided by the district heating system and the onsite solar thermal system. With the help of the electrical and thermal storage a shift of the excessive onsite generated electricity and heat is performed.

6. CONCLUSIONS

The optimization shows that the usage of local combined heat and power (CHP) systems can reduce the energy costs by about 22%. A reduction of the CO_2 emissions can be done as well, but not hand in hand with a decrease in yearly energy costs.

The cost minimization run results in a decrease of the energy costs by about 22%, the CO_2 emissions increase by around 18%. This is the recommendation for the Campus Pinkafeld from an economic point of view.

The CO_2 emission minimizing run decreases the CO_2 emissions by about 87% and increases the energy costs by around 50%. This is the recommendation for the Campus Pinkafeld from an environmental point of view.



Notes on abbreviations:
DH = district heating, ES = electricity from supplier, PV = photovoltaic, ST = solar thermal
ICE = internal compustion engine (CHP), HS = heat storage, BS = battery system, NG = natural

Figure 6-1: Comparison of all optimization runs at Campus Pinkafeld (DER-CAM, CET)

EnRiMa starts where DER-CAM stops and will explicitly incorporate uncertainty, e. g., in tariffs or weather forecasts, etc. EnRiMa will be focused on required temperature levels and will consider uncertainties as e. g. building occupation and weather. Therefore, EnRiMa will be more flexible in choosing the optimal DER usage considering the operations temperature of the building. Also, EnRiMa will consider passive measures as building retrofits. Nonetheless, the runs with DER-CAM show that a CO_2 minimization strategy will be very difficult to implement at Pinkafeld since the low CO_2 emissions from the district heating plant make this very difficult and would require a lot of PV and solar thermal making the energy supply expensive.

7. ACKNOWLEDGMENT

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The Distributed Energy Resources Customer Adoption Model (DER-CAM) has been designed at Lawrence Berkeley National Laboratory (LBNL) and is owned by the U.S. department of Energy. In course of this work the free available web-version of DER-CAM was used.

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