Using waste heat from data centers in different climate zones

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Data centers use 21% of all electricity in the IT services sector [1] and are accounted for about 0,28% of global greenhouse gas emissions [2]. The utilization of waste heat nowadays is already frequently adapted in technological processes with high temperature occurring. It can be a simple way to increase the energy efficiency of currently operating data centers. Typical IT equipment, such as servers used in modern data centers, is designed to operate in temperatures that does not exceed 25°C [3]. It poses a fundamental requirement on data centers to use highly effective cooling systems. Those systems are prone to produce large amounts of waste heat which are usually generated in the form of preheated fluids with temperature that usually does not exceed 100°C [3].

The potential of reusing the heat generated in data centers has been reviewed in [4]. Authors presented number of currently available and developmental low-grade waste heat recovery techniques including district heating with their operational requirements in order to assess the suitability and effectiveness of each technology for data center applications.

The economic assessment of investing in data center waste heat utilization has been conducted in [5]. According to authors investing the waste heat utilization technology can be profitable business opportunity for large data centers. On the other hand simulations presented in [6] shows that small data centers could meet the heat demand within their nearby neighborhoods and decentralizing data centers can provide free and efficient heating for residential buildings.

The article analyzes the possibility of using waste heat from data centers located in different climate zones, according to the Köppen climate classification [7]. In order to assess the maximum amount of living space for which adequate living conditions can be provided throughout the year by reusing heat from data centers, the longstanding data about average temperatures from [8] was used.

Energy efficiency of data centers

Nowadays data centers are usually evaluated by the Power Usage Effectiveness (PUE). This factor was firstly proposed by the non-profit organization The Green Grid. In 2016 it was included in European standards [9] and now is widely used in grading the sustainability of data centers. PUE is calculated as the ratio of total electricity consumed in the data center to electricity consumed by IT devices. Average value of PUE worldwide is 2.0 [10], which means that for each two Watts of energy retrieved by the data center, only one Watt is used to power IT equipment. This high value imposes the need for searching for new ways to optimize energy efficiency of these type of objects.

The average age of a data center in the world is nine years [11]. It is estimated that all objects older than seven years are already obsolete, not only because of their out-of-date equipment but often due to the lack of possibility for renovation [11]. These conditions spawn the opportunity to form new outlines for finding viable locations for data center.

There is also steady ascend in requirement for heating energy. Based on the data from 2015 almost 1821 TWh of heat energy is required annually worldwide [12]. It is estimated that 20% to 30% of waste heat from all technological processes can be recovered [12]. The main issue is relatively low temperature of waste heat generated in data centers which seems to pose a fundamental limit to its use on a large scale [13]. Because of the inability to disrupt the cooling process of IT devices, necessary for the proper operation of the entire network infrastructure in data centers, it seems unfeasible to increase the amount of heat released despite the dynamic increase in energy consumption of the servers themselves [13]. Current efforts are focusing primarily on optimizing the efficiency of energy recovery processes from fluids at temperatures not exceeding 100°C [13].

Assessing the exact temperature of waste heat in data center is problematic. Values varies even inside servers' room. Constructing a waste heat recovery system requires very specific decisions about the exact location of energy retrieving unit. The immediate vicinity of servers reaches the temperature of 60-80°C as the return air near CRAC unit is only about 30°C [14]. These low temperatures are usually not enough to power any heat to power units, mostly due to rather low efficiency of Carnot cycle (maximum theoretical efficiency reaches about 18% for 90°C waste heat) which allow to gain up to 5% net electricity [14]. Therefore, the heat should be used as unprocessed as possible.

The gathered data provided both a model of the energy intake of data centers as well as an accurate description of the way it is used within these facilities (Fig.1). Power costs states about 10% of all operational costs in average data centers [15]. It is estimated to be 100 times higher than for regular office spaces [3].

As shown in Fig.1 majority of electric energy is consumed by IT equipment. About 71% of electricity intake is used to power and maintain continuous workflow of average data center. It is vital to emphasize that as much as 15% of electric energy is usually used to maintain proper conditions within servers' room. This part of energy intake seems to be most proper for reusing or recovering. Example of such a system is shown in Fig. 2. There are data centers that use waste heat nowadays, but this is usually limited to maintaining adequate conditions inside the facility.

Methodology and results

An analysis on the potential use of waste energy was done in few phases. It is vital to emphasizes that the aim of all calculations presented in this paper is to estimate the maximum potential of waste heat energy and compare the possibility of it reusage in different climate zones. This process is highly dependent on many factors such as:

- type of district heating, its length and heat carrier used;
- small changes to an average temperature which can occur within one climate zone;

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- legal requirements;
- location of the data center within urban zones.

Finding a most viable solutions for data center that is supposed to power district heating was treated as an optimization problem between three factors:

- heat energy required throughout the year;
- length of heating seasons;
- possible energy loss.

The main goal of the paper was to compare climate conditions and find out where waste heat can be utilized most effectively. It was assumed that there are places with climate conditions that allow to reuse waste heat throughout the year as a source of residential heating for vast parts of urban zones. Firstly, the amount of heat generated by three types of commonly used servers in data centers [18, 19, 20] at various load levels was estimated. This data was compared with the necessary surface that must be provided for this type of equipment and the energy potential per square meter of server space was calculated

As shown in Table 1, there is big difference between each model heat generation with only little change in required space. The most energy consuming one generates over three times as much heat as the least energy consuming. It is vital to emphasizes that final values are based on heat generated by the servers working at standard load (about 60% dependent on producer [18, 19, 20]). The results may differ for other levels of load but even when the server works at or below 20% of its capacity, the power consumption is up to 60-90% of the maximum [21].

It is difficult to precisely estimate the heat loss in district heating. It is highly dependent on the type of pipeline transport, its length, thermal conductivity and outdoor temperatures. The type of materials used in district heating pipelines varies all over the world and can determine energy losses. Important aspect of assessing heat loss in transportation is also the distance. There is a linear relationship between the length of the pipeline and net loss of thermal energy inside. What is vital is to show comparison between climate zones as this factor can possibly determine viability of treating waste heat as power source.

The next step was to estimate residential heating demand for individual locations in each month. For each climate zone one city was chosen and average diurnal month temperature from these cities were used in further calculations (Table 2) [8].

Then the heating and cooling energy requirement was calculated. If housing spaces required cooling energy the value is a negative number. Due to variation of recommended value for the temperature provided inside housing areas in different countries all calculations were based on [22]. The required energy for one square meter was calculated for each month in each climate zone (Table 3). In order to obtain average worth only positive values where taken under consideration. It was assumed that obtaining cooling energy from waste heat is not efficient enough in order to sustain a viable system. It was established that

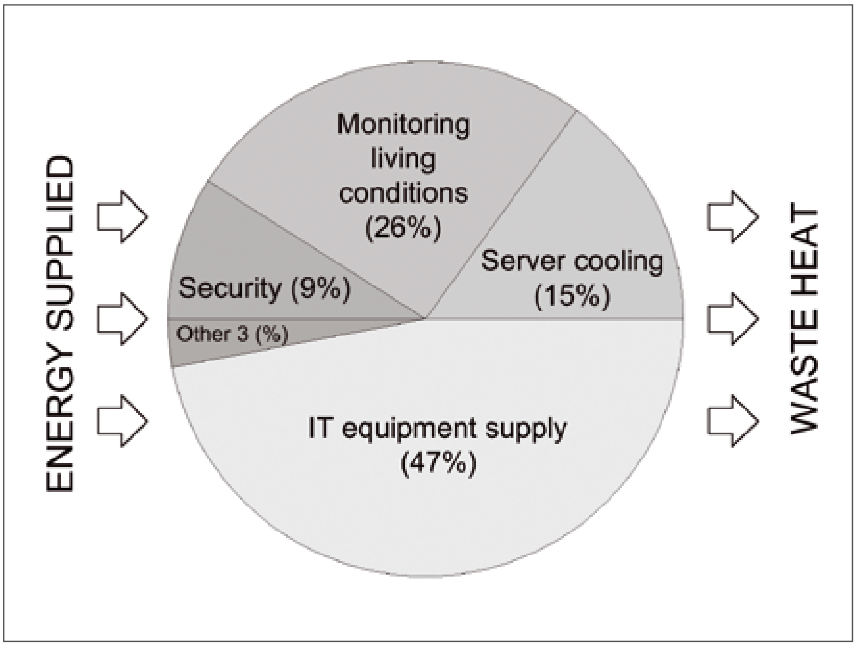

Fig 1. Energy flow in typical data center. Based on [16]

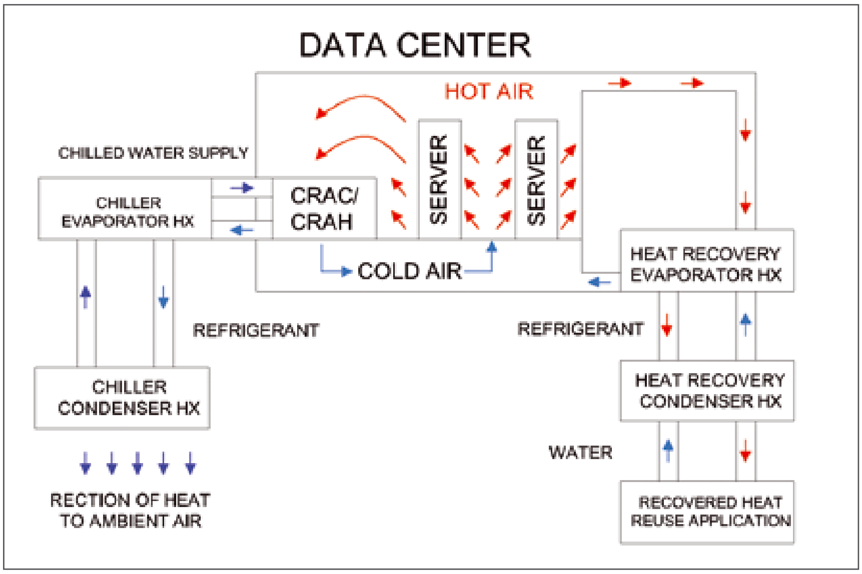

Fig. 2 Example of waste heat recovery system in data center with server rooms containing Computer Room Air Conditioning (CRAC) or Computer Room Air Handler (CRAH). Red color symbolizes hot air. Light blue symbolizes cold air. Dark blue symbolizes cold water. The scheme based on [17].

Table 1. Heat power generate by servers [15] [16] [17].

Producer	Model	W	W	W	m^2	W	W/m^2
		Idle	Maximum load	Standard load	Required space	By rack	Ratio
Dell	PowerEdge R420	397,40	679,05	625,12	0,7239	26255,06	36268,91
IBM	System x3650	360,48	993,51	596,11	0,765	12518,24	16363,71
HP	ProLiant BL460c Gen10	897,09	1313,84	1319,11	0,757682	42211,61	55711,52

▶

Table 2. Average diurnal temperature in each month in each climate zone [8].

		Climate zone symbol in Köppen climate classification																					
		AF	AM	Aw	BSH	BSk	BWh	BWk	Csa	CSb	Cfa	Cwa	Cfb	Cwb	Cfc	DFA	Dwa	DFb	DWB	DFc	DWc	ET	EF
Month of the year	I	21,7	19,8	26,8	20,2	-1,0	28,7	-0,7	7,4	9,1	22,6	16,6	20,1	21,8	-0,2	-7,5	-4,0	-1,9	-12,1	-15,1	-19,3	-32,4	-41,0
	II	21,7	20,0	26,8	21,4	0,9	27,9	2,9	10,3	9,8	22,3	17,4	20,3	21,6	0,5	-7,4	-1,4	-0,4	-8,8	-11,1	-16,6	-32,7	-47,0
	III	22,0	21,8	27,3	23,0	3,6	25,0	5,5	12,0	11,7	20,9	20,2	18,6	19,8	0,8	-1,9	5,4	3,1	-1,8	-5,6	-7,6	-28,7	-39,0
	IV	22,2	23,6	27,9	24,7	8,6	20,4	9,1	14,7	13,3	18,2	24,1	15,3	17,4	3,1	9,4	13,5	9,4	5,6	3,2	1,9	-18,8	-31,0
	V	23,0	25,6	28,0	25,4	14,0	15,4	14,1	18,3	15,2	15,4	27,6	12,4	15,8	6,6	17,1	19,9	14,5	10,6	9,6	9,5	-4,1	-20,0
	VI	23,6	27,2	27,6	24,7	19,4	12,4	19,1	21,9	18,0	13,8	29,4	10,2	15,1	9,2	21,9	24,3	17,5	14,5	13,7	15,3	7,0	-16,0
	VII	24,0	28,1	27,4	24,1	22,8	11,5	23,3	24,1	19,5	13,7	29,1	9,4	15,8	11,0	24,3	26,3	20,0	19,0	15,8	17,8	9,6	-12,0
	VIII	24,5	27,5	27,7	24,2	21,8	14,1	21,9	23,7	19,6	14,9	28,8	10,4	16,8	10,6	23,0	24,9	19,2	21,2	14,6	15,6	6,6	-18,0
	IX	24,6	25,7	28,0	23,9	16,9	18,5	17,0	22,0	18,6	16,2	27,5	12,1	18,3	7,9	16,2	19,9	14,2	17,0	9,6	9,1	0,0	-21,0
	X	24,2	23,0	28,3	22,9	11,1	22,7	10,9	17,8	15,8	18,0	25,2	14,2	19,5	4,7	8,5	13,1	9,1	9,9	4,3	1,1	-13,6	-35,0
	XI	23,2	20,7	27,9	21,6	4,0	25,9	3,9	11,7	12,2	19,9	21,7	16,2	20,3	1,6	0,6	4,7	4,6	0,2	-7,0	-9,6	-26,9	-42,0
	XII	22,2	22,2	27,4	20,2	0,1	27,7	-0,5	7,5	9,6	21,0	18,5	18,3	19,0	0,1	-4,0	-1,8	0,5	-8,4	-13,1	-16,5	-32,3	-38,0
	AVG.	23,1	23,8	27,6	23,0	10,2	20,9	10,5	16,0	14,4	18,1	23,8	14,8	18,4	4,7	8,4	12,1	9,2	5,6	1,6	0,1	-13,9	-30,0

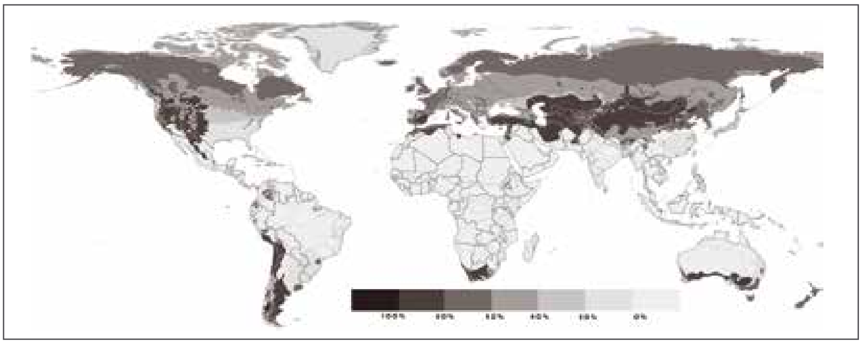

Fig. 3. Rating of the possibility of utilizing waste heat for living space heating in different climate zones in comparison to the best theoretical results.

heating season last only when the difference between temperature required inside and average temperature outdoor varies by more the 5° C. In order to include the impact of different heating seasons length in different climate zones the correction factor was proposed in form of squared ratio of heating season length and one year- values shown in Table 3.

Correction factor was introduced in order to emphasis the need for continues workflow of the district heating system powered by data centers. Some climate zones can be instantly excluded as a possible location of data center-based district heating. Not only are those climate zones with no heating requirement throughout the year but also zones with very short heating seasons and no extremely cold periods.

The final step was to compare these values and assess the effectiveness of data centers located in different climates. The maximum area of housing space for which heating energy is provided by one square meter of server room was calculated. Then the results were multiplied by the correction factor estimated before. Non-zero values for climate zones are shown in Table 4 categorized by server type and climate zone.

The power generated by individual server types is significantly different and has a decisive impact on the use of waste heat as a power source for municipal heating networks. The demand for heating energy is different in various climate zones, in some cases even non-existent. The results as the percent of the best outcome are depicted in Fig. 3. Only three climate zones reached at least 60% as other 12 attain non- zero results. Eight climate zones were graded 0. Those are: AF, AM, AW, BSh, BWh, Cwa, Cwb, Cwc.

Conclusions

Key factor for determining the feasibility of using data centers waste heat as a power source for district heating is its location. Creating an appropriate waste heat recovery system seems possible and is already in use on small scale. This paper highlights climate zones in which the use of waste heat energy from data centers as a source of heating would be the most efficient. Best results of simulations conducted in this research are reached in three climate zones. The subpolar oceanic climate has achieved the best score. The next most proper climate zones are cold dessert climate and cold semi- arid climate.

Analysis has shown, by utilizing the correction factor, that it is not most efficient to construct data centers in the coldest climate possible. There are climate zones where energy from data center could be used to power district heating throughout the year for vaster areas. For zones that reached zero percent results, it is necessary to convert waste heat into another form of energy as there are no obvious application for reusing heat. Further analysis should focus on different factors, which must be considered in order to design district heating system powered by data center, such as calculating exact heating energy requirement or estimating energy losses for selected locations.

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Table 3. Heating and cooling energy requirement (kW/m2) and correction factor for each climate zone.

	Climate zone symbol in Köppen climate classification																						
	AF	AM	Aw	BSH	BSk	BW	BW	Csa	CSb	Cfa	Cwa	Cfb	Cwb	Cfc	cwc	DFA	Dwa	DFb	DW	DFc	DW	ET	EF
I	-7,00	-1,76	-21,04	-2,86	55,52	-20,49	54,69	32,39	-4,79	-9,47	7,05	-2,59	-7,27	53,32	10,36	73,42	63,78	58,00	86,09	94,35	105,9	142,0	165,6
II	-7,00	-2,31	-21,04	-6,17	50,29	-23,24	44,78	24,40	-4,79	-8,65	4,85	-3,14	-6,72	51,39	7,05	73,15	56,62	53,87	77,00	83,34	98,48	142,8	182,2
III	-7,82	-7,27	-22,42	-10,58	42,85	-23,24	37,62	19,72	-2,04	-4,79	-2,86	1,54	-1,76	50,56	3,47	58,00	37,90	44,23	57,72	68,19	73,70	131,8	160,1
IV	-8,37	-12,23	-24,07	-15,26	29,08	-19,39	27,71	12,28	4,02	2,64	-13,60	10,63	4,85	44,23	3,47	26,88	15,59	26,88	37,34	43,95	47,53	104,5	138,1
V	-10,58	-17,74	-24,35	-17,18	14,21	-14,43	13,94	2,37	10,91	10,36	-23,24	18,62	9,25	34,59	3,19	5,67	-2,04	12,83	23,57	26,33	26,60	64,06	107,8
VI	-12,23	-22,14	-23,24	-15,26	-0,66	-9,47	0,17	-7,55	15,59	14,76	-28,20	24,68	11,18	27,43	5,95	-7,55	-14,16	4,57	12,83	15,04	10,63	33,49	96,83
VII	-13,33	-24,62	-22,69	-13,60	-10,02	-6,44	-11,40	-13,60	17,52	15,04	-27,37	26,88	9,25	22,47	8,98	-14,16	-19,66	-2,31	0,44	9,25	3,75	26,33	85,81
VIII	-14,71	-22,97	-23,52	-13,88	-7,27	-6,72	-7,55	-12,50	16,69	11,73	-26,55	24,13	6,50	23,57	9,25	-10,58	-15,81	-0,11	-5,62	12,56	9,80	34,59	102,3
IX	-14,98	-18,01	-24,35	-13,05	6,22	-7,55	5,95	-7,82	12,56	8,15	-22,97	19,44	2,37	31,01	8,15	8,15	-2,04	13,66	5,95	26,33	27,71	52,77	110,6
X	-13,88	-10,58	-25,17	-10,30	22,20	-9,20	22,75	3,75	8,43	3,19	-16,63	13,66	-0,94	39,82	9,53	29,36	16,69	27,71	25,50	40,92	49,74	90,22	149,1
XI	-11,13	-4,24	-24,07	-6,72	41,75	-11,40	42,03	20,54	2,37	-2,04	-7,00	8,15	-3,14	48,36	12,01	51,11	39,82	40,10	52,22	72,04	79,21	126,8	168,4
XII	-8,37	-8,37	-22,69	-2,86	52,49	-15,81	54,14	32,11	-1,21	-5,07	1,82	2,37	0,44	52,49	11,73	63,78	57,72	51,39	75,90	88,84	98,21	141,7	157,4
*	0	0	0	0	25,03	0	24,15	12,09	6,43	4,62	1,14	10,95	2,88	37,05	7,49	31,98	24,01	26,70	35,91	46,23	50,38	85,59	126,39
**	0,00%	0,00%	0,00%	0,00%	66,7%	0,00%	66,7%	41,7%	25,0%	16,7%	0,00%	41,7%	0,00%	100%	0,0%	58,3%	58,3%	58,3%	66,7%	83,3%	75,0%	100%	100%
***	0,00	0,00	0,00	0,00	0,44	0,00	0,44	0,17	0,06	0,03	0,00	0,17	0,00	1,00	0,00	0,34	0,34	0,34	0,44	0,69	0,56	1,00	1,00

* Average annual heating requirement (kW/m^2), ** Ratio of heating season length in the year (%), *** Correction factor

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[22] PN-B-02025:2001 Obliczanie sezonowego zapotrzebowania na ciepło do ogrzewania budynków mieszkalnych i zamieszkania zbiorowego

Abstract: The article analyzes in which climatic zones the use of waste heat from data centers as a source of urban district heating would be the most efficient. The assessment methodology was based on a comparison of heat energy generated by servers with the demand for heating power in different climate zones. The analyzes carried out showed that the most appropriate climate zones for reusing waste heat from data centers are subpolar oceanic climate, cold dessert climate and cold semi-arid climate.

Keywords: data center, waste heat, heat energy recovery, energy efficiency.

Streszczenie: Wykorzystanie ciepła odpadowego z centrów danych w różnych strefach klimatycznych. W artykule przeanalizowano, w których strefach klimatycznych wykorzystanie energii odpadowej z centrów danych jako źródła ciepła do ogrzewania powierzchni mieszkalnych byłoby najbardziej efektywne. Metodologię oceny oparto na porównaniu energii cieplnej generowanej przez serwery z zapotrzebowaniem na moc grzewczą w różnych strefach klimatycznych. Przeprowadzone analizy wykazały, że najbardziej odpowiednie strefy klimatyczne dla wykorzystywania energii odpadowej z centrów danych to subpolarny klimat oceaniczny, zimny klimat pustynny i zimny klimat półpustynny.

Słowa kluczowe: centrum danych, ciepło odpadowe, odzyskiwanie energii cieplnej, efektywność energetyczna

Table 4. Theoretical maximum residential area (m^2) that can be heated by 1 m^2 of server room

		Climate zone symbol in Köppen climate classification														
		BSk	BWk	Csa	CSb	Cfa	Cfb	Cfc	DFA	Dwa	DFb	DWB	DFc	DWc	ET	EF
Server type	Dell	644	667	520	353	218	575	979	386	514	462	449	545	405	424	287
	IBM	291	301	235	159	98	259	442	174	232	209	203	246	183	191	130
	HP	989	1025	799	542	335	883	1504	593	790	710	689	837	622	651	441