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Technical and Economic Analysis of an Absorption Chiller

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Abstract: The research conducted includes a technical and economic analysis of an absorption chiller used for cooling a hotel in the city of Plovdiv - Bulgaria. The main objectives of the analysis are: to establish whether the project is profitable or not; to provide an opportunity to compare different project options; to provide information to a bank or other financing institution as to whether the financial indicators of the project satisfy its requirements for financing such a project. The following are determined: investment costs for the project, energy costs during operation of the installation, operating costs during operation of the installation. Based on this, annual energy savings, simple payback period of the installation, net present value, net present value coefficient, payback period and internal rate of return of the installation were calculated. An energy-economic analysis was performed using the "full cost" method of absorption and vapor-compressor water chillers. The analysis shows that for the specific site; the absorption chiller is a more energy-efficient air conditioning solution than a chiller operating on the principle of a vapor-compressor refrigeration machine.

Keywords: Energy efficiency, Absorption chiller, Heating, Air-conditioning

Introduction

Nowadays, the energy efficiency of air conditioning systems serving buildings located in large cities is essential in two aspects: to ensure low energy costs during their operation, thereby reducing the costs of their payment and to guarantee low carbon emissions into the environment, thereby preserving the purity of the air in urban conditions (Doty, 2016; Iliev et al., 2023; Turner, 1997). Very often, pipes with hot water pass near air-conditioned buildings, which provide heat for heating and domestic hot water supply from the heat energy company as a supplier to the consumers. (Capehart et al., 2012; Kaloyanov et al., 2020; Thuman & Younger, 2008). The use of thermal energy during the summer season for cooling commercial and public buildings instead of electricity will satisfy wishes of suppliers and consumers, as follows:

- customer will pay lower energy bills for cooling, which in turn is necessary to maintain comfortable microclimate parameters in the building during the summer months. In addition to lower costs, the problem of price predictability is also particularly relevant from the perspective of using electricity, taking into account the dynamics of the liberalized market. Another important circumstance that will be seen from the analysis is that the customer will not have either investment or operating costs for the project, they will be borne by the district heat energy company;
- supplier will sell thermal energy during the summer season, when its consumption is reduced due to its use mainly for domestic hot water (DHW). In this case, the supplier's interest is whether the project will be profitable, whether the profits from the sale of thermal energy will cover the investment costs and operation cost for the implementation of the project (Wyrwa & Chen, 2019; Yongprayun et al., 2007). Through this

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type of project supplier is guaranteed a consistent consumer of thermal energy over a long period of time, sufficient investment and payment of the project (Amiri et al., 2021; Nérota et al., 2021).

Method

The study looks at replacing a compressor chiller, operating on the principle of a vapor compressor refrigeration machine with an absorption chiller. Based on known climate data for the city, the annual energy costs of the installation were calculated. To show economic profitability the following technical and economic indicators were calculated: net annual savings B, net present value NPV, net present value coefficient NPVQ, payback period PB, and investment pay over period PO (Rasheva, 2011). A comparison of the total costs (investment + operating + energy costs) for air conditioning with an absorption chiller and a compressor chiller was made. The two chillers were selected to have the same cooling capacity, and their costs were calculated under the same operating conditions.

Technical and Economy Analysis

The investment costs of the project are calculated using the formula:

$$I_0 = I_{pj} + I_{cp},$$

where: I_{pj} - project costs, €;
I_{cp} - capital costs, €.

Specific investment cost for cooling for absorption and compressor chiller is determined by the formula:

$$SIC_A = \frac{I_o}{ECCA.n}$$

$$SIC_C = \frac{I_o}{ECCM.n}$$

where: ECCA = ECCM requires cooling capacity for the building, MWh/year.
n - duration of the technical/economic life of the facility.

The prices for thermal and electrical energy PT and PE re determined according to current prices at the time of analysis (Energy and water regulatory commission, 2023), (National Statistically Institute Bulgaria, 2023). The costs of operation and maintenance of the facilities are determined by the formula:

$$\Delta O\&M = OPC_E + OPC_A$$

where: OPC_E - operation costs for depreciation, preventive maintenance, maintenance, materials, spare parts, wages, €/year;

OPC_A - unforeseen operation costs (up to 2 percent of investment costs), €/year.

Specific operation cost for cooling for absorption and compressor chiller is calculated using the formula:

$$S\,(\Delta O\&M)_A = \frac{(\Delta O\&M)_A}{ECCA}$$

$$S\,(\Delta O\&M)_C = \frac{(\Delta O\&M)_C}{ECCM}$$

Energy costs are calculated according to the formula:

$$EC_A = \frac{ECCA}{COP_A}.PT + N_i.PE$$

$$EC_C = \frac{ECCM}{COP_C}.PE + N_i.PE$$

$$N_i = P_i.\tau$$

where: COP_A, COP_C are coefficient of performance of absorption and compressor chiller, -;
N_i is annual electricity consumption of the facilities, MWh/year.
P_i - total installed electrical power of the equipment, kW.
τ - working hours on electrical equipment, hours/year

Specific energy cost is calculated according to the formula:

$$SEC_A = \frac{EC_A}{ECCA}$$

$$SEC_C = \frac{EC_C}{ECCM}$$

Total specific cost for cooling for absorption and compressor chiller is determined by the formula:

$$SEC_{A,tot} = SEC_A + SICC_A + S(\Delta O\&M)_A$$

$$SEC_{C,tot} = SEC_C + SICC_C + S(\Delta O\&M)_C$$

Exploitation costs for cooling for absorption and compressor chiller are calculated according the formula:

$$EC_{tot} = EC + \Delta O\&M$$

Energy savings (net anual savings B = ES) are determined by the formula:

$$ES = EC_{tot,C} - EC_{tot,A}$$

$$ES = \frac{EC_{tot,C} - EC_{tot,A}}{EC_{tot,C}}.100,\%$$

The payback period is calculated according to the formula:

$$PB = \frac{I_0}{B}$$

The net present value of the project is determined by the formula:

$$NPV = \sum_{i=1}^{n} \frac{B}{(1+r)^i} - I_0$$

$$NPV = B.\frac{1-(1+r)^{-n}}{r} - I_0$$

Coefficient of net present value is calculated according to the formula:

$$NPVQ = \frac{NPV}{I_0}$$

The pay over period PB = n is determined by the formula:

$$NPV = B.\frac{1-(1+r)^{-n}}{r} - I_0 = 0$$

The internal rate of return IRR = r is calculated according to the formula:

$$NPV = B.\frac{1-(1+r)^{-n}}{r} - I_0 = 0$$

where: n_r - base interest rate, %;
r - real interest rate, %

The results of the analysis will provide an answer to the question of whether the project is economically profitable for heat supplier if it fully assumes the investment and operating costs of the project.

Results and Discussion

A feasibility study of an absorption chiller for cooling a hotel in the city of Plovdiv, Bulgaria, was conducted. The building itself consists of a hotel part and a casino, with a total area of about 10 000 m^2, and has an air conditioning installation powered by low-efficiency compressor chiller. In a part of the building, the climate control system was designed, it was solved with 158 units of fan convectors and a separate cooling section in the general ventilation system. The total cooling capacity of the units is 1074 kW. The premises of the casino are equipped with air conditioning installation, designed with a fan convector and a cooling section in general ventilation. The new absorption chiller is selected based on the installed cooling capacity in hotel part and casino of the hotel, as well as on the design temperature regime of the existing installation, which is 7/12 ºC. The flow rate is changed by adjusting a proportional valve, controlled by controller on the chiller. The heat carrier is a temperature regime of 89/75ºC.

Along with the cooled water, the absorption chiller was also connected in parallel to two horizontal insulating buffer tanks, each with a capacity of 6 m^3, located in close proximity to the cooling chiller. Circulation of the coolant between buffer and absorption chiller is carried out by two circulation pumps with a flow rate of 189 m^3/h, a pressure of 16 m H_2O and installed electrical power 11kW, 400V. For normal operation, it is necessary to remove the heat released by absorption chiller to the atmosphere. This is done through water-cooling circuit. There are three cooling towers each with a cooling capacity of 900 kW. Circulation to cooling water is also carried out through two circulation pumps with a flow rate of 372 m^3/h, pressure of 26 m H_2O and installed electrical power 30 kW, 400V. Temperature regime for cooling water is 28/34 ºC. For normal work on the irrigation water-cooling circuit and the water-cooling circuit, it is necessary to constantly compensate the evaporation of water. The supplied additional water must be treated to achieve the desired quality. Preparation for added water is also carried out through cascade processing in an automatic hydrothermal installation, a filter-chlorinator and a reverse osmosis module. The cooling power consumption is measured by ultrasonics heat meter with a nominal flow rate of 60 m^3/h and a maximum flow rate of 120 m^3/h, DN100, PN16.

The climate data are necessary for the correct selection of the facilities, as well as for assessing the cooling of the building for what period of time it will be carried out. Data for outside temperatures for Plovdiv are shown on Table 1. The data show that the duration of the cooling will be for a period of about five months a year, with the most intensive being during three of them. The required cooling capacity for the building ECC = ECCA = ECCM = 934.04 MWh/year. The information was captured by a heat meter that measured the consumption of heat energy for cooling during the operation of the compressor chiller. The prices for thermal and electrical energy are PT = 70.54 €/ MWh and PE = 231.23 €/ MWh (Energy and water regulatory commission, 2023; National Statistical Institute Bulgaria, 2023).

Table 1. Climate data – outdoor temperature

Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abs. max temp., ºC	22.5	25.6	29.8	34.2	36.0	39.8	45.0	42.2	38.7	36.8	28.0	22.1
Avg. max. temp., ºC	5.0	8.0	12.0	18.0	24.0	28.0	31.0	30.0	26.0	20.0	11.0	7.0
Avg. temp., ºC	1.0	3.0	7.2	12.3	17.4	21.7	23.9	23.3	19.1	13.0	6.8	2.3
Avg. min temp., ºC	-3.0	-2.0	2.0	6.0	11.0	15.0	17.0	16.0	13.0	8.0	2.0	-1.0
Abs. min. temp., ºC	-31.5	-29.1	-17.9	-5.2	-0.3	4.5	8.2	5.6	0.2	-5.8	-17.4	-22.5

Based on a preliminary estimate and known investment costs for installation with compressor chiller, the following values have been adopted for needs of the analysis:

$I_{pj,A}$ = 4090.33 €, $I_{cp,A}$ = 139071.40 €, $I_{pj,C}$ = 4090.33 €, $I_{cp,C}$ = 120909.67 €.

Based on calculations and known operational costs for installation with compressor chiller, the following values were adopted for the needs of the analysis:

$OPC_{E,A}$ = 7572.44 €/ year, $OPC_{A,A}$ = 2863.24 €/ year, $OPC_{E,C}$ = 7572.44 €/ year, $OPC_{A,C}$ = 2500.00 €/ year.

Based at known technical parameters of absorption and compressor chiller, the following values were adopted for the needs of the analysis:

COP_A = 0.71, COP_C = 2.05; P_i = 50 kW (see Table 2); τ = 1720 h/year

Table 2. Installed total installed electrical power of the equipment

Equipment	Installed electrical power, kW
Absorption chiller – auxiliary equipment	7.3
Cooling tower	11.1
Circulation pumps	30.0
Controler	1.6
Total	50.0

The duration of the technical/economic life of the facility is n= 25 years, n_r = 2.96 %, r = 3.00 %. In Table 3 a comparison between absorption and compressor chiller total cost are shown.

Table 3. Absorption and compressor chiller total cost

Parameters	Absorption chiller	Compressor chiller
ECC = ECCA = ECCM, MWh/year	934.04	934.04
COP, -	0.71	2.05
Energy carrier	water	electricity
I_0, €	143161.73	125000.00
SIC, €/ MWh	6.13	5.35
ΔO&M, €/ year	10435.68	10072.44
S(ΔO&M), €/ MWh	11.17	10.78
EC, €/year	112684.63	125240.94
SEC, €/ MWh	120.64	134.09
SEC_{tot}, €/ MWh	137.95	150.22
EC_{tot}, €/year	123120.31	135313.38
ES = B = $EC_{tot,C}$ – $Ec_{tot,A}$, €/ year	12193.07	-
Life n, year	25.00	25.00
PB, years	11.74	-
NPV, €	69157.97	-
NPVQ, -	0.48	-
PO, years	14.70	-
IRR, %	6.9 %	-
ES, %	9.01	-

Energy savings without reducing installation and operating costs when replacing a compressor chiller with an absorption chiller have been calculated. In Table 4, net annual savings, calculated on base of total costs and cash flow, are shown. In Table 5 a comparison between absorption and compressor chiller total cost are shown. Energy savings are calculated when replacing a compressor chiller with an absorption chiller, taking into account the additional savings from investment and operating costs incurred by the district heat company.

Table 4. Net annual savings and cash flow (total costs)

Period (Years)	ES = B, €/ year	Cashflow, €
0	0.00	-143161.73
1	12193.07	-130968.66
2	12193.07	-118775.59
3	12193.07	-106582.52
4	12193.07	-94389.46
5	12193.07	-82196.39
6	12193.07	-70003.32
7	12193.07	-57810.25
8	12193.07	-45617.18
9	12193.07	-33424.11
10	12193.07	-21231.05
11	12193.07	-9037.98
12	12193.07	3155.09
13	12193.07	15348.16
14	12193.07	27541.23
15	12193.07	39734.30
16	12193.07	51927.36
17	12193.07	64120.43
18	12193.07	76313.50
19	12193.07	88506.57
20	12193.07	100699.64
21	12193.07	112892.71
22	12193.07	125085.77
23	12193.07	137278.84
24	12193.07	149471.91
25	12193.07	161664.98

Table 5. Absorption and compressor chiller total cost (additional savings)

Parameters	Absorption chiller	Compressor chiller
ECC = ECCA = ECCM, MWh/year	934.04	934.04
COP, -	0.71	2.05
Energy carrier	water	electricity
I_0, €	143161.73	125000.00
SIC, €/ MWh	6.13	5.35
ΔO&M, €/ year	10435.68	10072.44
S(ΔO&M), €/ MWh	11.17	10.78
EC, €/year	112684.63	125240.94
SEC, €/ MWh	120.64	134.09
SEC_{tot}, €/ MWh	137.95	144.87
EC_{tot}, €/year	123120.31	135313.38
ES* = B = $EC_{tot,C} - Ec_A$, €/ year	22628.75	-
Life n, year	25.00	25.00
ES, %	16.72	-

In Table 6, net annual savings, taking into account the additional savings from the investment and operating costs incurred by the district heat company and cash flow are shown. In Table 7, total (installation + operation + energy) costs are shown. In “0 year” investment costs were reported, in “1 year” total operating and energy costs were calculated, and in each subsequent year, total operating and energy costs were calculated, increased by 3.00 % compared to the previous year.

Table 6. Net annual savings and cash flow (with additional savings)

Period (Years)	ES = B, €/ year	Cashflow, €
0	143161.73	143161.73
1	22628.75	165790.48
2	22628.75	188419.23
3	22628.75	211047.98
4	22628.75	233676.72
5	22628.75	256305.47
6	22628.75	278934.22
7	22628.75	301562.97
8	22628.75	324191.72
9	22628.75	346820.47
10	22628.75	369449.21
11	22628.75	392077.96
12	22628.75	414706.71
13	22628.75	437335.46
14	22628.75	459964.21
15	22628.75	482592.96
16	22628.75	505221.70
17	22628.75	527850.45
18	22628.75	550479.20
19	22628.75	573107.95
20	22628.75	595736.70
21	22628.75	618365.45
22	22628.75	640994.19
23	22628.75	663622.94
24	22628.75	686251.69
25	22628.75	708880.44

Table 7. Total (installation + operation + energy) costs

Period (Years)	Compressor chiller	replacement without reduction cost	replacement with zero investment and operation costs
0	143161,73	143161.73	-143161.73
1	123120.31	123120.31	112684.63
2	126813.92	126813.92	116065.17
3	130618.33	130618.33	119547.12
4	134536.88	134536.88	123133.53
5	138572.99	138572.99	126827.54
6	142730.18	142730.18	130632.37
7	147012.09	147012.09	134551.34
8	151422.45	151422.45	138587.88
9	155965.12	155965.12	142745.51
10	160644.08	160644.08	147027.88
11	165463.40	165463.40	151438.72
12	17042.30	170427.30	155981.88
13	175540.12	175540.12	160661.33
14	180806.32	180806.32	165481.17
15	186230.51	186230.51	170445.61
16	191817.43	191817.43	175558.98
17	197571.95	197571.95	180825.75
18	203499.11	203499.11	186250.52
19	209604.08	209604.08	191838.04
20	215892.20	215892.20	197593.18
21	222368.97	222368.97	203520.97
22	229040.04	229040.04	209626.60
23	235911.24	235911.24	215915.40
24	242988.58	242988.58	222392.86
25	250278.24	250278.24	229064.65
Total cost, €	5058426.13	4632037.56	3965236.88
Economy,%	-	-8.43	-21.61

Conclusion

The technical and economic analysis shows the following results:

- Variant for replacing a compressor chiller with an absorption chiller (without additional savings from investment and operating costs): calculated value of energy savings ES = 12193.07 €/ year, which is equal to 9.01 % of exploitation costs of compressor chiller, payback period PB = 11.74 years, pay over period PO = = 14.70 years, positive values of net present value NPV = 69157.97 €, net present value coefficient NPVQ = 0.48 and internal rate of return IRR = 6.9 %. The difference in total costs for a period of 25 years is 426388.57 € which is 8.43 % less than total (investment + operation + energy) costs of compressor chiller.
- Variant for replacing a compressor chiller with an absorption chiller (with additional savings from investment and operating costs): calculated value of energy savings ES = 22628.75 €/ year, which is equal to 16.72 % of exploitation costs of compressor chiller. The difference in total costs for a period of 25 years is 1093189.25 € which is 21.61 % less than total (investment + operation + energy) costs of compressor chiller.

The analysis shows that the option with additional savings is more economically viable. The user of the installation has a free period during which the installation is paid for by the supplier of heat energy for a zero cost of thermal energy used. In addition, for the agreed period, maintenance of the installation is carried out by the district heat company, and the user does not pay any costs for these activities. The district heat company guarantees sales of thermal energy both in summer and in winter for a specific user, which makes the return on the investment costs of the project undertaken by him very fast.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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