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Shared and intake energy related to a building served by a hybrid source - heat pump with boiler

Energie comună și absorbită aferentă unei clădiri deservite de o sursă hibridă - pompă de căldură cu boiler

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Rezumat: Evaluarea aporturilor si consumurilor energetice aferente utilizarii pompelor de caldura pentru deservirea cladirilor in ceea ce priveste incalzirea spatiilor si/sau prepararea apei calde de consum comporta 3 etape principale de calcul : evaluarea coeficientului de performanta al pompei de caldura, COP, determinarea temperaturii exterioare de echilibru, teE si calculul puterilor de baza ale pompei: puterea termica livrata la condensator, puterea termica absorbita la vaporizator, puterea electrica utilizata si puterea termica livrata de centrala termica. In lucrarea se prezinta in detaliu evaluarea fiecareia din aceste 4 tipuri de puteri energetice. Procedura de lucru descrisa permite utilizarea programului de calcul al BIN-urilor lunare.

Cuvinte cheie: sursă hibridă, pompă de căldură cu boiler

Abstract: The assessment of shared and consumed energy related to heat pumps for servicing buildings in terms of space heating and/or the preparation of domestic hot water involves 3 main stages of calculation: assessment of the heat pump's coefficient of performance, COP, determination of the external equilibrium temperature , teE and the calculation of the basic powers of the pump: the thermal power delivered to the condenser, the thermal power absorbed by the evaporator, the electrical power used and the thermal power delivered by the heating plant. The paper presents in detail the evaluation of each of these 4 types of energy powers. The described work procedure allows the use of the monthly BIN calculation program.

Key words: hybrid source, heat pump with boiler

1. Introduction

The evaluation of input energy and consumption related to heat pumps to solve the problems of space heating and the preparation of domestic hot water related to buildings has been a constant concern in the authors' research. The current work is based on the evaluation of the COP of the heat pump using the isentropic energy efficiency of the heat pump, ε^{IZ}_{pc}, {1} as the central core. A first step in the calculation of the assessment of energy inputs and consumptions is the evaluation of the COP values of the heat pump in the different situations of the couple of temperatures of the cold, θ_{vp} and hot θ_{cd} environments. A second important stage is evaluation of equilibrium external

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temperature, teE, temperature for which the thermal power delivered to the pump condenser is equal to the required thermal power of the consumer. The third stage is the effective evaluation of the thermal and electrical powers involved in the operation of the source-consumer system on each BIN separately and of the energies on each BIN, for each month and for the whole year, for space heating and/or hot water preparation.

2. Procedure

The procedure that will be presented is based on the evaluation of the isentropic energy efficiency of the heat pump, ε^{IZ}_{pc}. A number of parameters related to the heat pump and the consumer are considered known, such as:

a. The temperatures of the cold and warm environments in which the evaporator, θ_{vp}, and the condenser of the machine are located, θ_{cd}.

b. Isentropic efficiency, η_{iz}.

c. Electrical motor efficiency, η_{el}.

d. Electrical motor maximum power, P_{EL};

e. Building transfer capacities for heating and DHW, H_{inc}, H_{acc};

f. Hot and cold DHW temperatures : t_{ac} si t_{ar};

g. In the case of space heating, account will be taken of the simplified calculation relationship of the heat agent input temperature in the central heating installation.

$$t_T = \left(1 + \frac{t_{T0} - t_{i0}}{t_{i0} - t_{e0}}\right) \cdot t_{i0} - \frac{t_{T0} - t_{i0}}{t_{i0} - t_{e0}} \cdot t_e \tag{1}$$

Heat pump isentropic efficiency will be :

$$\varepsilon^{IZ}_{pc} = U \cdot dt^{-V}$$
$$dt = t_{cd} - t_{vp} \tag{2}$$

$$\varepsilon^{IZ}_{pc} = M \cdot \varepsilon^{C}_{pc} - N$$
$$\varepsilon^{C}_{pc} = \frac{t_{cd} + 273.15}{t_{cd} - t_{vp}} \tag{3}$$

To simplify evaluation it was proposed relations (3).

Constant values :

$$U = 705.53;\ \ V = 1.284;$$
$$M = 0.9676;\ \ N = 1.6081; \tag{4}$$

To be possible heat transfer at evaporator respectively condenser, logarithmic temperature differences are:

$$\Delta t = \Delta t_{vp} = \theta_{vp} - t_{vp}$$
$$\Delta t = \Delta t_{cd} = t_{cd} - \theta_{cd} \tag{5}$$

Below examples use $\Delta t = 5\ ^{o}C$.

Evaporation and condensing temperatures:

$$t_{vp} = \theta_{vp} - \Delta t$$
$$t_{cd} = \theta_{cd} + \Delta t \tag{6}$$

COP evaluation use ecuation (7)

$$COP = \eta_{el} \cdot \varepsilon_{PC} = \eta_{el} \cdot \left[1 + \eta_{iz} \cdot \left(\varepsilon_{PC}^{IZ} - 1\right)\right] \tag{7}$$

3. External equilibrium temperature evaluation, t_{eE},

The equilibrium external temperature, teE, is defined as the external temperature for which the thermal power delivered to the pump condenser is equal to the required thermal power of the consumer. The case of the space heating consumer and the case of the hot water preparation consumer will be analyzed separately.

a. Space heating

$$COP_E \cdot P_{EL} = H_{inc} \cdot \left(t_{i0} - t_{eE}\right) \tag{8}$$

Simplified form of equation (8):

$$\frac{t_{i0} - t_{eE}}{COP_E} = \frac{P_{EL}}{H_{inc}} \tag{9}$$

In relation (9) the equilibrium external temperature is found only in the left member of the relation, the quantities in the right member being given. An analysis of the correlation between the external equilibrium temperature, teE and the P_{EL}/H_{inc} ratio was carried out and the obtained result is presented below:

$$t_{eE} = -2.4958 \cdot \left(\frac{P_{EL}}{H_{inc}}\right) + 15.361 \tag{10}$$

b. Daily Hot Water production:

$$COP_E \cdot P_{EL} = H_{acc} \cdot \left(t_{ac} - t_{ar}\right) \tag{11}$$

Extracting COP from eq. (11):

$$COP_E = \frac{t_{ac} - t_{ar}}{P_{EL}/H_{acc}} \tag{12}$$

An analysis was made of the correlation between the equilibrium external temperature, teE contained in the left member of the relationship (12) and the right member of the relationship (12) and the obtained result is presented below:

$$t_{eE} = -1.7191 \cdot \left(\left(t_{ac} - t_{ar}\right) \Big/ \left(\frac{P_{EL}}{H_{acc}}\right)\right)^2 + 24.338 \cdot \left(\left(t_{ac} - t_{ar}\right) \Big/ \left(\frac{P_{EL}}{H_{acc}}\right)\right) - 56.032 \tag{13}$$

4. The effective evaluation of the thermal and electrical powers involved in the operation of the source-consumer system on each individual BIN and of the energies on each BIN, for each month and for the whole year, for space heating and/or hot water preparation

For heating:

a. If $\mathbf{t_e} < \mathbf{t_{eE}}$ then $P_{EL} = P_{el\_max}$ and COP vs thermal powers evaluation for each external temperature are:

$$\begin{aligned} &P_{pc} = COP \cdot P_{EL} \\ &P_{inc} = H_{inc} \cdot (t_{i0} - t_e) \\ &P_{ct} = P_{inc} - P_{pc} \\ &P_{vp} = (COP - \eta_{EL}) \cdot P_{EL} \end{aligned} \tag{14}$$

b. If $\mathbf{t_e} > \mathbf{t_{eE}}$ then $P_{pc} = P_{cons}$ and thermal powers evaluation for each external temperature are:

$$\begin{aligned} &P_{inc} = H_{inc} \cdot (t_{i0} - t_e) \\ &P_{pc} = P_{inc} \\ &P_{el} = P_{pc} / COP \\ &P_{ct} = 0 \\ &P_{vp} = (COP - \eta_{EL}) \cdot P_{el} \end{aligned} \tag{15}$$

Daily Hot Water preparation:

a. if $\mathbf{t_e} < \mathbf{t_{eE}}$ than $P_{EL} = P_{el\_max}$ and:

$$\begin{aligned} &P_{pc} = COP \cdot P_{EL} \\ &P_{acc} = H_{acc} \cdot (t_{ac} - t_{ar}) \\ &P_{ct} = P_{acc} - P_{pc} \\ &P_{vp} = (COP - \eta_{EL}) \cdot P_{EL} \end{aligned} \tag{16}$$

b. If $\mathbf{t_e} > \mathbf{t_{eE}}$ then $P_{pc} = P_{cons}$ and:

$$\begin{aligned} &P_{acc} = H_{acc} \cdot (t_{ac} - t_{ar}) \\ &P_{pc} = P_{acc} \\ &P_{el} = P_{pc} / COP \\ &P_{ct} = 0 \\ &P_{vp} = (COP - \eta_{EL}) \cdot P_{el} \end{aligned} \tag{17}$$

The energies on BINs are obtained by multiplying the powers with the duration of the BIN. To determine the monthly energy values, the resulting values for the BINs of the respective month are collected.

Definition of energy coverages:

- Heat pump coverage factor:

$$GA_{pc} = P_{pc} / P_{cons} \tag{18}$$

- Electrical energy coverage factor :

$$GA_{el} = P_{el} / P_{cons} \tag{19}$$

- Boiler coverage factor:

$$GA_{ct} = P_{ct} / P_{cons} \tag{20}$$

- Renewable energy coverage factor :

$$GA_{vp} = P_{vp} / P_{cons} \tag{21}$$

5. Results

The evaluation of energy inputs and consumption for a space heating and hot water preparation consumer presented in the previous chapters follows the order in which the calculations must be performed. The first action undertaken is the establishment of the BINs corresponding to the locality where the building for which the calculations are made is located. Establishing BINs is a preliminary step that must be carried out before starting the procedure described so far based on climate data. Enter the data related to the consumer, Hinc, Hacc, the temperature of hot water, tac, and cold water, tar, and the data related to the heat pump: ηel, ηiz, M, N, PEL, and proceed to the first stage of establishing the COP of the heat pump. Next, the external equilibrium temperature, teE, is established, according to the procedure described in point 3. Next is the application of point 4 for the assessment of thermal and electrical powers: Ppc, Pvp, Pel, Pct and their corresponding energies: Epc, Evp, Eel, Ect , obtained by multiplying the powers with the durations of the BINs. In this way, a tabular presentation of the results appears, as the program created by the authors, which also includes the program for creating the BINs that was written in [2], appears. In this way, an automatic calculation tool is obtained that solves the energy aspects related to the implementation of a heat pump with mechanical compression of air-water type values together with the consumer's classic heating plant.

As an example, we present the results obtained with the mentioned program for a building with space heating utility located in Odorheiul Secuiesc. The presented results, as can be seen for the month of December, are extended to evaluate all the year and show the sum of the energies for all months of the year. It can be seen in table 1, which follows in columns 2 and 3, the data of the BINs, (t_e and N_{ore}) for the month of December. In column 2, the values of the external equilibrium temperature, t_{eE}, were placed, further following 4 groups of parameters. For COP calculation (columns 5, 6, 7, 8 and 9), for power evaluation (columns 10, 11, 12, 13 and 14), for energy evaluation (columns 15, 16, 17, 18 and 19) and finally group of degrees of energy coverage (columns 20, 21, 22 and 23)

Example: Odorheiul Secuiesc

Tabel 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Decembrie	**teE**	**te**	**ore**	**tcd**	**tvp**	**eCpc**	**elZpc**	**COP**	Pcons	Pel	Pcd	Pvp	Pct	Econs	Eel	Ecd	Evp	Ect	GApc	GAel	GAct	GAvp
	oC	**oC**	**h**	**oC**	**oC**				W	W	W	W	W	kWh	kWh	kWh	kWh	kWh				
BIN 1	-4.605	-6.24	59.52	42.891	-11.240	5.838	4.041	3.090	372608	113600	350985	248745	21623.02	22177.63	6761.472	20890.63	14805.3	1287.002	0.942	0.305	0.058	0.668
BIN 2	-4.605	-3.92	178.56	41.309	-8.920	6.260	4.450	3.384	339664	100383	339664	249319.3	0	60650.4	17924.38	60650.4	44518.46	0	1	0.296	0	0.734
BIN 3	-4.605	-1.6	267.84	39.727	-6.600	6.754	4.927	3.727	306720	82291.61	306720	232657.6	0	82151.88	22040.98	82151.88	62315	0	1	0.268	0	0.759
BIN 4	-4.605	0.72	178.56	38.145	-4.280	7.337	5.492	4.134	273776	66225.81	273776	214172.8	0	48885.44	11825.28	48885.44	38242.69	0	1	0.242	0	0.782
BIN 5	-4.605	3.04	59.52	36.564	-1.960	8.040	6.171	4.623	240832	52093.02	240832	193948.3	0	14334.32	3100.577	14334.32	11543.8	0	1	0.216	0	0.805
												Energ. Lunare		228199.7	61652.7	226912.7	171425.2	1287.002				
												Energ. Anuale MWh		1267.241	328.7461	1250.88	955.0089	16.36091				

Nomenclature :
t_e – external temperature, °C;
t_{e0} – design external temperature, °C;
t_{eE} – external equilibrium temperature, °C;
t_{T0} – design maximum turn temperature, °C;
t_T – turn temperature, °C;
t_{i0} – design comfort temperature, °C;
t_{ac} – DHW temperature, °C;
t_{ar} – cold water temperature, °C;
θ_{vp} – evaporation environment temperature, °C;
θ_{cd} – hot environment temperature, °C;
t_{vp} – evaporation temperature, °C;
t_{cd} – condensing temperature, °C;
Δt – logarithmic temperature difference, °C;
η_{iz} –isentropic efficiency, -;
η_{EL} – electrical compressor motor efficiency, -;
ε^C_{pc} – Carnot efficiency, -;
ε^{IZ}_{pc} – heat pump isentropic efficiency, -;
COP – Coeficient of Performance, -;
P_{el} – heat pump electrical power consumption, W;
P_{EL} – maximum heat pump electrical power consumption, W;
P_{pc} – condensing power, W;
P_{vp} – evaporation power, W;
P_{ct} – boiler power, W;
P_{cons} (P_{inc}, P_{acc}) – design thermal power consumption, W;
H_{inc} – building heating capacity, W/m^2;
H_{acc} – DHW heating capacity, W/m^2;
E_{pc}, E_{mf}, E_{el}, E_{ct}, E_{cons} – BIN energies; W.h;
GA_{pc} – heat pump coverage factor, -;
GA_{el} – electrical energy coverage factor, -;
GA_{ct} – boiler coverage factor, -;
GA_{vp} – renewable coverage factor, -;
U, V, M, N – procedure design parameters,

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