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THERMAL AUDIT OF APARTMENT UTILIZING TWO HEAT SOURCES

Principal Assistant. Pencho Zlatev, PhD
Agrarian and Industrial Faculty
Department of Heat, Hydraulics and Environmental Engineering
University of Ruse "Angel Kanchev"
E-mail: pzlatev@uni-ruse.bg

Principal Assistant. Ivaylo Nikolaev, PhD
Agrarian and Industrial Faculty
Department of Heat, Hydraulics and Environmental Engineering
University of Ruse "Angel Kanchev"
E-mail: nikolaev@uni-ruse.bg

Abstract: *The article assesses the cost of heating a typical apartment in a multi-story residential building using an air-to-water heat pump and central heat supply. The evaluation was made for both heating and domestic hot water energy consumption of the apartment. The determination of heat loads is according to the current European standards and the modified bin method.*

Keywords: *Heat pump air to water, central heat supply, heat pump COP.*

INTRODUCTION

With the pronounced trend of rising energy prices, the question arises of combining two or more sources of energy in residential buildings to optimize the cost of heating and air conditioning. The consumption of heat in residential buildings depends on several factors such as climate, type of building single-family or multifamily, thermal insulation used heat source and degree of automation of the processes for maintaining the parameters of the microclimate. The report carried out an analysis of the energy consumption of an apartment located on a typical floor in a multi-family multi-story residential building, which is a common case in Bulgaria.

EXPOSITION

Description of the object subject of the survey

The dwelling presented in the report is located on the 10th floor of a multi-story residential building, and figure 1 presents its plan. The calculated heating load for each room is shown in Fig. 1, using the methodology of EN 12831 (DIN EN 12831-1).

When determining the load, the following assumptions are made: the adjacent dwellings on the same floor and those on the floor below and above the apartment are heated and maintain an average temperature of +18 ^{o}C (economy mode). Part of the apartment is adjacent to an unheated staircase and elevator and in these rooms, it is assumed that the temperature will be +8 ^{o}C. In the apartment, all living rooms are heated by maintaining a comfortable regime of +22^{o}C and in the sanitary rooms, the bathroom and toilet maintain a temperature of +24^{o}C.

The exterior walls of the apartment are reinforced concrete with a thickness of 25 cm and are thermally insulated with insulation with a thickness of 5 cm on the southern façade and 8 cm on the northern façade. The insulation is laid on the outside. The interior walls are brick and not thermally insulated except for the internal walls between the bedroom and elevator and stairs. These walls have insulation with a thickness of 5 cm laid on the internal surface. The floor and ceiling of the apartment are reinforced concrete and are also not thermally insulated. The windows are double glazing of PVC frame. Internal doors are standard without thermal insulation properties.

In Table 1. a summary of the walls windows and floors is provided. The values of the heat transfer coefficients of the individual elements are calculated according to the following standards: general method (EN ISO 6946), windows and doors (EN ISO 10077-1).

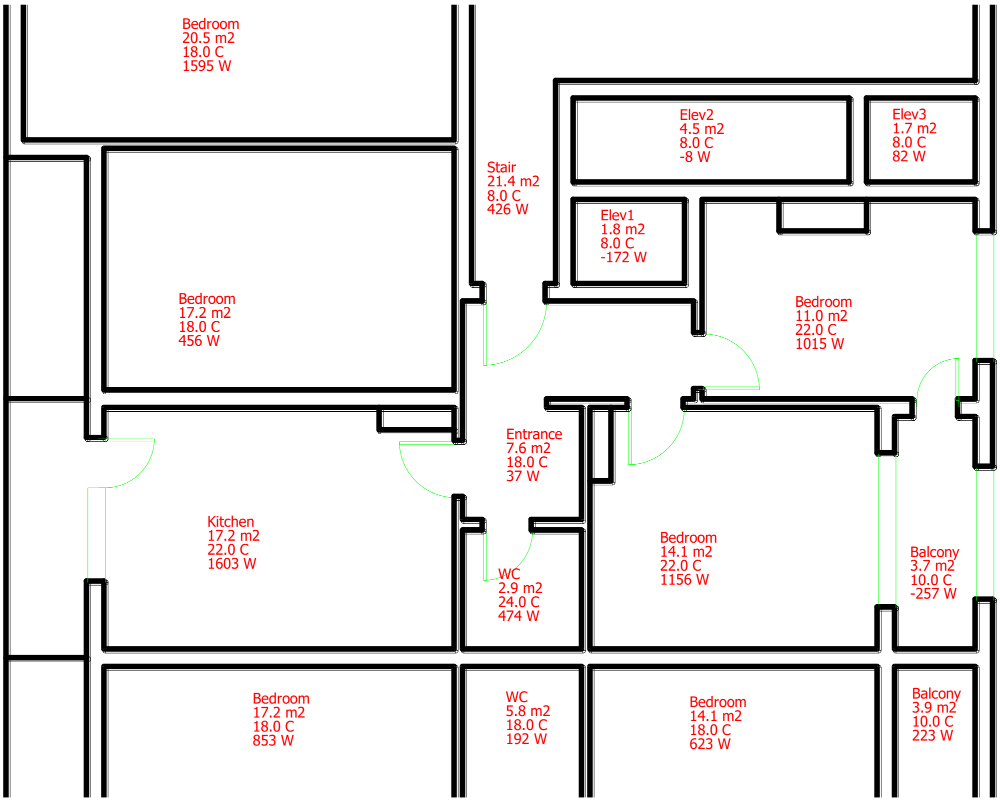


Fig. 1. Plan of the apartment and heating load by rooms

Examples of the user code used in different enclosures in Table 1: IW250 – internal wall with thickness 250mm; IW250_ins5 – internal wall with thickness 250 mm and insulation with thickness 5cm; EW250- external wall with thickness 250 mm; IF – intermediate floor; W1-window type 1; IDX/200 – internal door with standard width and height 200 cm.

Table 1. Areas and heat transfer coefficients of the enclosures

Type	**User code**	**Area, [m^2]**	**U, [W/m^2,C]**
Interior walls	IW250	122.87	3.2
Interior walls	IW120	72.03	3.77
Interior walls	IW250_ins5	15.67	0.62
Exterior walls	EW250	125.2	1.17
Exterior walls	EW250_ins8	14.23	0.33
Exterior walls	EW250_ins5	6.87	0.46
Windows	W1	2.97	1.4
Exterior windows	W1	5.93	1.4
Doors	IDX/200	9.33	2.6
Exterior doors	IDX/200	1.3	2.6
Slabs	IF	126.1667	3.77

Calculation results

Table 2 presents the results of the calculation of the heating load in the individual rooms of the apartment using the said methodology. Exceptions in the internal calculation temperature are for a glazed terrace where it is assumed not to exceed +10^{o}C.

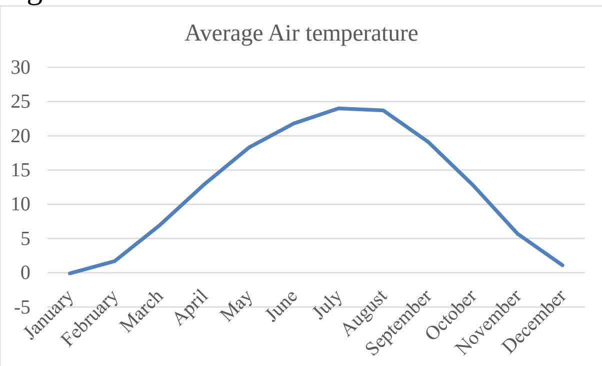
When calculating the heating load, the ventilation and infiltration in the building are also considered, showing in the Leak-factor column the multiple of air exchange for each room.

Table 2. Calculated heating load by rooms in the apartment

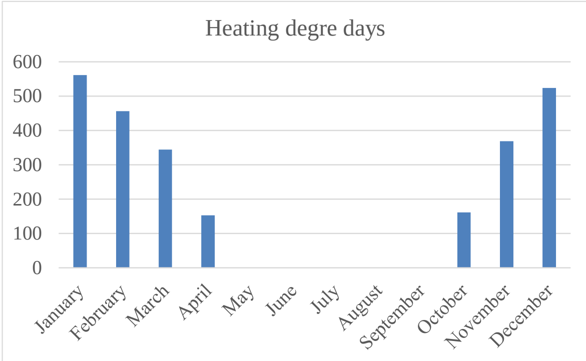
Room name	Ti, [°C]	Te, [°C]	Leak-factor, n [h^{-1}]	Height, [mm]	Heat loss [W]	Heat loss [W/net m^2]
Kitchen	22	-17	0.5	2500	1603	93.2
WC	24	-17	1	2500	474	165.23
Entrance	18	-17	0.5	2500	37	4.9
Bedroom	22	-17	0.5	2500	1156	81.91
Bedroom	22	-17	0.5	2500	1015	91.92
Balcony	10	-17	0.5	2500	(-257)	(-69)

The average specific net heat loss of all rooms in the apartment is 87.43 W/m^2. This value of the average heating load will be used in the analysis of the energy consumption of the apartment during the heating season.

The modified bin method shall be used to calculate the average heating load for each month (ASHRAE, 1985; Cane, R., 1979; Wortman, D., 1985). The input climate data for Ruse are presented in Figure 2.



a) Average ambient temperature



b) Heating degree days

Fig. 2. Climate data for Ruse

The assessment of the energy costs of the heating season is made on the assumption that the share of energy for domestic hot water will be a maximum of 50 % of the total heating load of the dwelling.

Under these conditions, and applying the modified bin method, the average heating load by month is calculated regardless of the type of heat source used. The results are presented in Fig. 3.

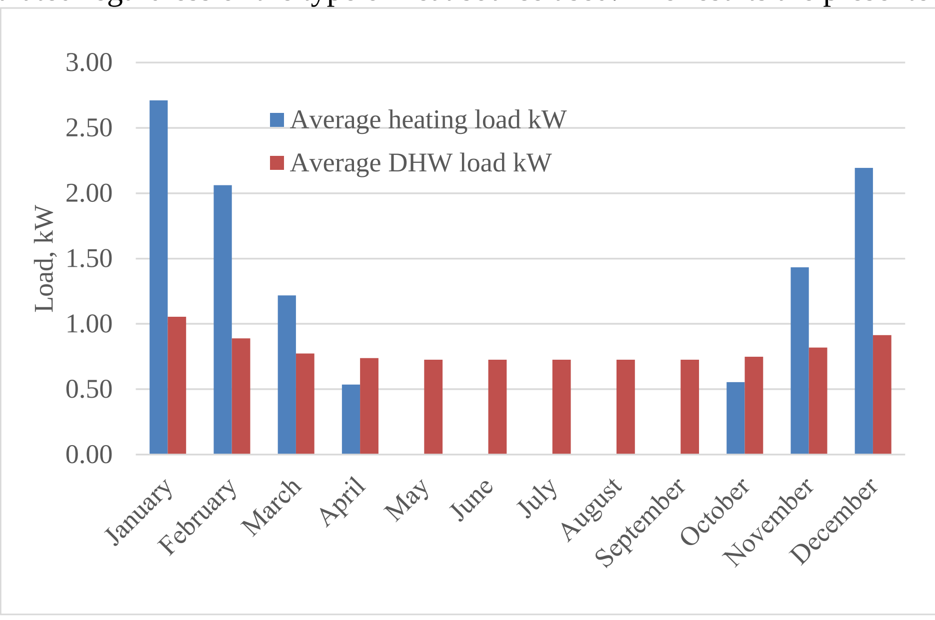


Fig. 3. Average heating and DHW load

A comparison of the heating and DHW expenses of the apartment was carried out using an air-to-water heat pump and central heat supply of the building. For this purpose, catalogue data from the producer of the heat pump Toshiba are used. The COP of the heat pump is provided by the producer in the range from -7 to +12°C external temperature. This data is approximated with a second-degree polynomial.

COP=3.14133536[-] + 0.162749075[(-)/C]*Ta + 0.00292027903[(-)/C^2]*Ta^2 (1)

T_a - the ambient temperature, °C.

The coefficient values in equation (1) and their standard error are presented in Table. 3.

Table 3. Second-order equation coefficients and their standard error

	Value	Std Error
a0	3.14E+00	5.60E-02
a1	1.63E-01	4.95E-03
a2	2.92E-03	2.80E-04

The second-order equation (1) will be used for the extrapolation of COP for the temperature range from -20°C to +25°C.

The results for the consumption of electricity and its price when using a heat pump for heating the apartment are presented in table 4.

Table 4. Electricity consumption and price for heating with heat pump

Month	**Average heating load**	**Average DHW load**	**days**	**COP DHW**	**COP**	**Energy for heating. ,**	**Price of electricity for heating,**	**Energy DHW,**	**Price of electricity for DHW,**
	kW	**kW**			**-**	**kWh/month**	**BGN/month**	**kWh/month**	**BGN/month**
January	2.71	1.05	31	3.13	3.13	645.25	114.54	250.88	44.53
February	2.06	0.89	28	3.43	3.43	404.22	71.75	174.52	30.98
March	1.22	0.77	31	4.40	4.40	205.95	36.56	130.57	23.18
April	0.53	0.74	30	5.73	5.73	67.21	11.93	92.74	16.46
May	0.00	0.73	31	7.10	7.10	0.00	0.00	76.10	13.51
June	0.00	0.73	30	8.08	8.08	0.00	0.00	64.71	11.49
July	0.00	0.73	31	8.73	8.73	0.00	0.00	61.87	10.98
August	0.00	0.73	31	8.64	8.64	0.00	0.00	62.52	11.10
September	0.00	0.73	30	7.32	7.32	0.00	0.00	71.45	12.68
October	0.55	0.75	31	5.70	5.70	72.24	12.82	97.76	17.35
November	1.43	0.82	30	4.16	4.16	247.70	43.97	141.73	25.16
December	2.19	0.91	31	3.32	3.32	490.91	87.14	204.43	36.29
Maximum	**4.46**					**2133.48**	**378.71**	**1429.29**	**253.71**

The electricity costs in table 4 are obtained using the average price of electricity per household of 0.177551 BGN/kWh.

The results for heat consumption and price are presented in Table 5.

The average price of heat used in this case is 112.23 BGN/MWh.

Table 5. Thermal energy consumption and price for heating and DHW

Month	**Average heating load**	**Average DHW load**	**days**	**efficiency**	**Energy for heating and DHW,**	**Price of thermal energy,**
	kW	**kW**		**-**	**MWh/month**	**BGN/month**
January	2.71	1.05	31	0.9	3.11	349.22
February	2.06	0.89	28	0.9	2.20	247.29
March	1.22	0.77	31	0.9	1.65	184.78
April	0.53	0.74	30	0.9	1.02	114.23
May	0.00	0.73	31	0.9	0.60	67.35
June	0.00	0.73	30	0.9	0.58	65.18
July	0.00	0.73	31	0.9	0.60	67.35
August	0.00	0.73	31	0.9	0.60	67.35
September	0.00	0.73	30	0.9	0.58	65.18
October	0.55	0.75	31	0.9	1.08	120.90
November	1.43	0.82	30	0.9	1.80	202.21
December	2.19	0.91	31	0.9	2.57	288.21
Maximum	4.46				**16.39**	**1839.24**

A practical interest in the specific case is the modification of the average heating load in a function of the average daily external temperature.

The results are presented in Figure 4 and are approximated with a third-degree polynomial.

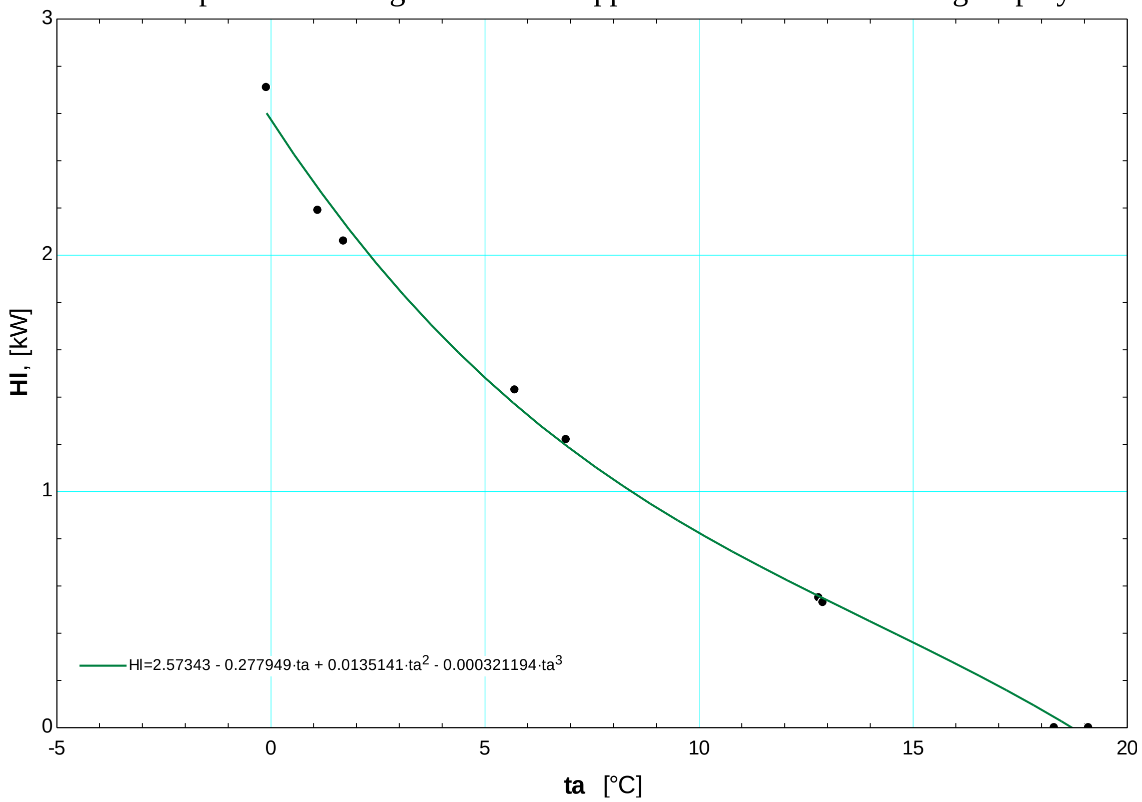


Fig. 4. Change of average heating load in temperature function

$$Hl=2.57342718 - 0.277948737*ta + 0.0135141348*ta^2 - 0.000321194052*ta^3 \quad (2)$$

t_a - the ambient temperature, °C, Hl is heating load in kW.

The statistical analysis of the coefficients in equation (2) is shown in table 6.

Table 6 Third-order equation coefficients and their standard error

	Value	Std. Error
a0	2.573427E+00	6.407843E-02
a1	-2.779487E-01	3.818776E-02
a2	1.351413E-02	5.010331E-03
a3	-3.211941E-04	1.716397E-04

Root mean square - 8.4080E-02; Bias -1.7468E-19; R2 – 99.55%

CONCLUSION

It is apparent from the analysis that the use of a heat pump is more economically advantageous than a centralized heat supply. However, at very low temperatures, the efficiency of the heat pump has dropped significantly, suggesting that in these periods the central heat supply should be used. It is, therefore, necessary to carry out further analysis based on an hourly change in the efficiency of the heat pump, to assess the cost of energy and possibly to adopt a strategy for working at night in December and January with the centralized heat supply.

With the help of dependency (2), it is possible to extrapolate the results in the case of lower daily average temperatures for the specific test site without the need to apply the modified BIN method.

REFERENCES

Cane R.L.D., A “Modified” BIN Method for Estimating Annual Heating Energy Requirements of Residential Air Source Heat Pumps, ASHRAE Journal, Vol.21, № 9, September 1979 p-60-63.

DIN EN 12831-1 Energy performance of buildings - Method for calculation of the design heat load - Part 1: Space heating load.

EN ISO 10077-1:2017 Thermal performance of windows, doors and shutters. Calculation of thermal transmittance General.

EN ISO 6946:2017 Building components and building elements. Thermal resistance and thermal transmittance. Calculation methods.

Wortman D. N., C. B. Christensen, Variable-Base Degree-Day Correction Factors for Energy Savings Calculations, Prepared under Task № 4151.34, Solar Energy Research Institute A Division of Midwest Research Institute 1617 Cole Boulevard Golden, Colorado 80401, August 1985.