CONFERINȚA NAȚIONALĂ de

TERMOTEHNICĂ

3 - 4 iunie 1994, TIMIȘOARA
ROMANIA
Ediția a IV-a

Comunicări științifice

Universitatea Tehnica Timișoara, România

Technical University Timișoara, Romania

NATIONAL CONFERENCE ON

THERMODYNAMICS

3 - 4 June 1994, TIMIȘOARA
Romania
Forth Edition

Proceedings

Vol. IV

ZONE-TEMPERATURE INFLUENCE ON HEAT RECOVERY IN AN INDUSTRIAL BUILDING WITH SEVERAL AVAILABLE HOT REFUSE FLOWS

N. LUKIC and M. BOJIC

Masinski fakultet, Univerzitet u Kragujevcu, Sestre Janjic 6, 34000 Kragujevac, Yugoslavia

Abstract-We use a recovery heat exchanger (RHE) in an industrial building to heat incoming air for space heating by using the heat contents of some of the refuse hot-air flows (RAF). Several RAFs are often available with different flow rates and temperatures. A proper scenario for use of their heat contents is essential for efficient management of the energy system. Using a steady-state, bottom-up approach, we have obtained a set of equations that we have linearized. Linear programming (LP) is then used and LINE software has been developed. This software has been used for an industrial building with three RAFs to obtain a use scenario corresponding to the highest energy-saving efficiency and minimum life-cycle costs of the RHE. Depending on the RHE size, temperatures of the colder and hotter zone of the industrial building and the outside temperature, we can recover the heat contents of different RAFs in different ways.

1. INTRODUCTION

Energy savings in industrial buildings are very important for national economy.[1] In industrial buildings recovery heat exchangers (RHE) are usually used to heat incoming air for space heating by using the heat contents of some of the refuse hot-air flows (RAF). Several RAFs are often available with different flow rates and temperatures.

A proper scenario for use of their heat contents is essential for efficient management of the energy system. Depending on the RHE size, temperatures of the hotter and colder zone and the outside temperature, we can recover the heat contents of different RAFs in different ways.

There are many methods for optimization of the building-energy performance.[2-8] We have optimized our non-linear energy system using LP.[9] This method is widely used in energy optimization of steam networks[10-12] or steal mills.[13] We did not find the application of the method in the field of heat recovery in industrial buildings.

Using steady-state bottom up approach as in Ref. 14, we have presented this energy system of an industrial building by heat-exchanger network. We have used Tayier series to make non-linear terms linear. We then use LP and develop LINE software.[15] For our industrial building we have obtained the scenario of use of its RAFs for the highest energy-saving efficiency and minimum life-cycle costs of RHE.

Although thermal comfort (TC) depends[16] on humidity, air velocity, radiant temperature, type of clothing, and activity of persons in the tool shop, we have taken thermal comfort to be function only of air temperature. We treat the case when we have air infiltration caused by wind. We have not taken into account the energy used for air flow in the system. When calculating the life-cycle costs of the RHE we did not take into account its present-worth factors, annual rate of energy price increase, discount rate, deprecations, maintenance cost and salvage value.

2. MATHEMATICAL MODEL

2.1. System Description

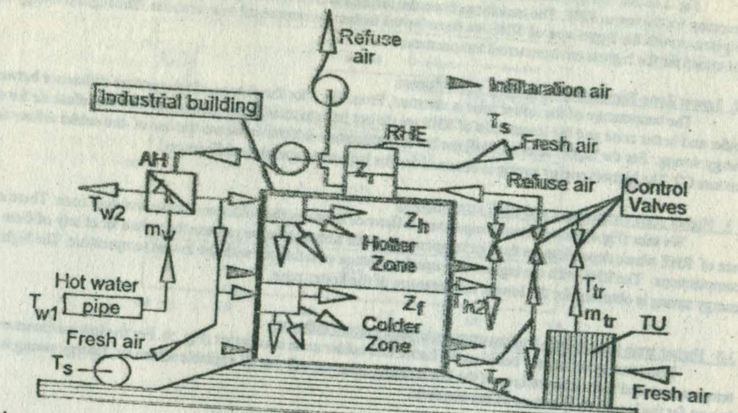
Fig. 1 shows an industrial building with two-temperature zones and a separate technology unit (TU). There are the hotter and colder building zones. In the hotter zone there are offices and in the colder building zone storage places. These zones are heated by using hot fresh air. This fresh air is preheated in RHE by using the refuse hot air. Then, the fresh air is heated in the air heater (AH). The part of this air is injected into the hotter building zone and another part into the colder building zone. Before its injection into the colder building zone the air is mixed with the cold fresh air. There are three RAFs: one from the hotter building zone (RAH), one from the colder building zone (RAC) and another is the refuse air (RAT) from the separate technology unit. Looking at their temperature and flow rate the most significant RAF is RAT. Examples are RATs generated by the compressor station or vacuum pumps combined with steam devices.

Fig.2 shows the heat-exchanger network used to model the energy system of Fig.1. The building zones with the higher and lower space temperatures are modeled as heat exchangers H and F, respectively. The hot water-transportation pipe from the hot water plant to the building is modeled as heat exchanger W.

The LP-objective function is the minimum of the energy expenditure

$$Q_w = m_w c_w (T_{w1} - T_{w2}). \quad (1)$$

Fig.1 Schematic of the industrial building with two-space-temperature zones.



This heat consumption also covers the heat losses during the hot water transport from the boiler to the industrial building. The money expenditure for heat and RHE during RHE-life cycle is

$$TE = [CE\, Q_w + CR\, Z_r]\, tA \quad (2)$$

where CE is the price of heat, CR the unit price of RHE and tA the useful life of RHE.

2.4. Nondimensional variables

We introduce the following nondimensional variables (subscript p stands for the initial quantities of the system)

$$(Z_r)_n = Z_r/(Z_r)_p,\ (T_{h2}-T_{f2})_n = (T_{h2}-T_{f2})/(T_{h2}-T_{f2})_p \quad (3)$$

$$(T_{h2})_n = T_{h2}/(T_{h2})_p,\ (T_s)_n = T_s/(T_s)_p, \quad (4)$$

$$S = [(Q_w)_p - Q_w]/(Q_w)_p,\ (CR)_n = CR/(CR)_p \quad (5)$$

Quantities $(T_{h2})_p$, $(T_{f2})_p$ and $(Q_w)_p$ are also these of the building without RHE.

3. RESULTS

LP model has been run for: c_w=4180 J/(kgK), Z_h=10000 W/K, Z_f=6000 W/K, Z_k=20000 W/K, $(Z_r)_p$=25000 W/K, m_w=15 kg/s, m_{tr}=20 kg/s, $(T_s)_p$=277 K, $(T_{h2})_p$=295 K, $(T_{h2}-T_{f2})_p$=5 K, T_{tr}=300 K, CE=4 10^{-6} DM/J, $(CR)_p$=5 10^{-5} DM-K/W, tA=20 years.

The LP optimization has given us the refuse air composition as it is shown in Table 1.

Table 1. The different cases of the RAF compositions used in RHE

#	Case	The RAF composition	Comments
1	C1	All of RAT	The highest temperature refuse flow
3	C2	All of RAT & RAH	The mixture with he medium temperature
5	C3	All of RAT, RAH & RAC	The mixture with the lowest temperature

3.1 Environmental temperature and RHE size influence

Fig. 2 shows that the increase of environmental temperature makes that the lowest temperature mixture is not interesting for the use in RHE. The transitions from the mixture with lower temperature to the mixture with higher temperature with the bigger size of RHE are done for the higher environmental temperatures. The highest energy saving is obtained for the highest environmental temperatures.

3.2 Lower Zone-Temperature and RHE size Influence

The temperature of the hotter zone is constant. From Fig 3 for the change of temperature difference between the colder and hotter zone and the lower sizes of RHE we do not have to change the composition of the refuse air for optimal energy saving. For the higher sizes of RHE the lower temperature difference means the use of the colder refuse-air mixture C3. The highest energy saving is obtained for the highest temperature differences.

3.3 Higher zone temperature and RHE size influence

We take (Fig.4) the constant temperature difference between the colder and hotter building zone. There is the size of RHE where depending on the exit temperature of the hotter zone we can use the refuse air of any of three compositions. The RHE with the highest size use the mixture of refuse air with the lowest temperature. The highest energy saving is obtained for the lowest temperatures of the hotter zone.

3.3 Higher zone temperature and environmental temperature influence

Temperature difference between the hotter and colder zone is constant (Fig. 5). For the low environmental temperatures and high temperatures of the hot building zone we will use all available refuse air. Energy saving is the lowest for the lowest temperature of environment.

3.4 Minimum money expenditure for heat and RHE during RHE-life cycle

Figure 6 shows that there is one environmental temperature where there is two values of RHE size for the minimum of money expenditure during RHE-life cycle.

4 CONCLUSION

The results are presented for a building with three RAFs. These results permit proper selection of scenario of use RAFs to avoid losses of energy and money while maintaining good thermal comfort in the building.

Fig.2 Energy savings vs the temperature of environmental air for three values of heat transmittance of the RHE

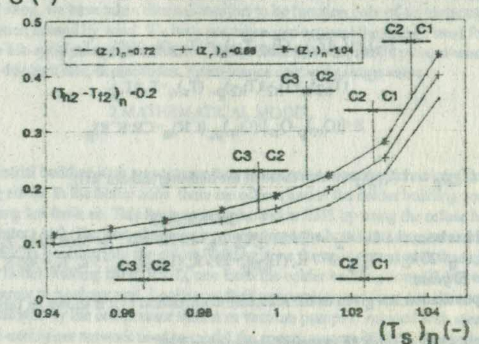


Fig.3 Regions of refuse air use for different values of heat transmittance of RHE and the temperature differences of two zones

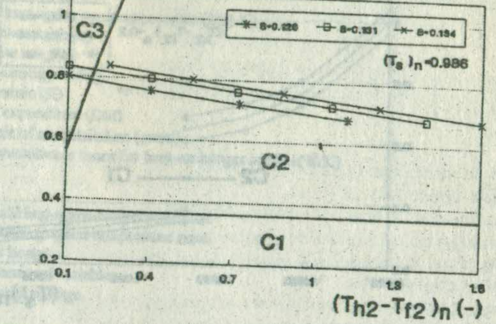


Fig.4 Regions of refuse air use for different values of heat transmittance of RHE and the exit temperature of air from the hotter zone

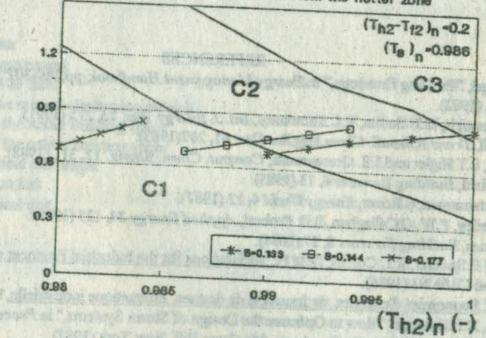


Fig.5 Regions of refuse air use for different values of environmental air temperature and the exit temperature of air from the hotter zone

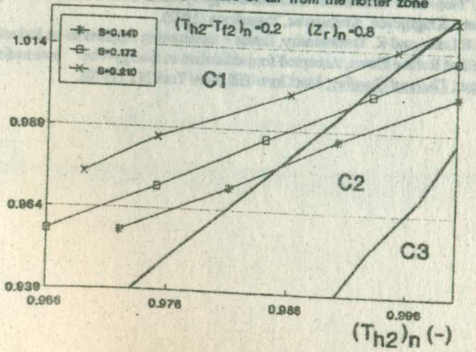
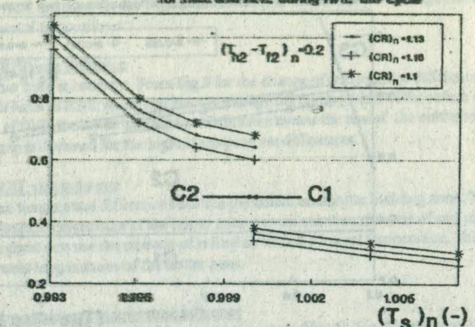


Fig.6 Heat transmittance of RHE vs the environmental temperature for the minimum money expenditure for heat and RHE during RHE-life cycle



REFERENCES

1. L.Spielvogel, "Building Envelope," in *Energy Management Handbook*, pp.269-302 ,W.Turner ed., John Wiley, New York (1982).
2. M.K.Deshmukh, M.S.Sodha, R.L.Showkney, *Int. J. Energy Res.* **15**, 275 (1991).
3. B.Linnhoff, *Trans IChemE. Chem.Eng.Res.Des.* **61**, 207(1983).
4. Y.D.Lang, L.T.Bigler and I.E. Greossmann, *Comput. Chem. Engng.* **12**, 311 (1988).
5. D.Bloomfield, *Building Services* **6**, 13 (1985).
6. E.Hampartsoumian, S.Roser, *Energy World* **4**, 12 (1987).
7. A.E. Adderley, P.W. O'Callaghan, S.D. Probert, *Applied Energy* **34**, 125 (1989).
8. M.J. Holmes, *Building Services* **8**, 27 (1986).
9. J.Banks, J.P.Spoerer, R.L.Collins, IBM PC applications for the Industrial Engineer and Manager, Prentice-Hall, Englewood Cliffs NJ (1986).
10. P.L. Goff, Economies d'energies, de francs ou de devises, Energetique industrielle, tome 2, Paris (1980).
11. J.K.Clark, N.E.Helmick, "How to Optimize the Design of Steam Systems," in *Process Energy conservation*, pp. 152-164 , R..Greene ed., Mc Graw Hill, New York (1982).
12. S.I.Gustafsson, B.G.Karlsson, *Heat Recovery Systems CHP* **11**,231 (1991).
13. A. Ziebik, *Heat in Industry* **4**, 7 (1988).
14. M. Bojic, *Energy-The International Journal* **18**, 49 (1993).
15. N. Lukic, "Non-linear behavior of industrial energy systems from the side of energy management," MS Thesis, Univerzitet u Kragujevcu, Kragujevac, Yugoslavia (1992).
15. M.Bojic, N.Lukic and K. Trnobransky, Linear programming Applied to an Industrial Building with Several Available Hot Refuse Flows, Accepted for publication in Energy-The International Journal, 1993.
16. P.O. Fanger, Thermal Comfort, MacGraw-Hill, New York NY (1970).

NOMENCLATURE

CE	= Energy price (DM/J)
CR	= RHE price (DM-K/W)
c.	= Specific heat under constant pressure (J/kg-K)
m	= Mass flow rate (kg/s)
Q	= Heat flow rate (W)
S	= Relative energy saving
T	= Temperature (K)
TE	= Money expenditure (DM)
tA	= Life cycle of an installation (years)
Z	= Heat transmittance times the heat-exchanger surface(W/K)

Subscripts

f	= Colder building-space-temperature zone
h	= Hotter building-space-temperature zone
k	= Space air heater
n	= Nondimensional variables
p	= Initial model settings
r	= RHE,
s	= Environment
t	= Separate technological unit
w	= Water
1	= Inlet
2	= Outlet

Abbreviations

AH	= Space heater
LP	= Linear programming
RAF	= Refuse hot air flow
RAT	= AF from the separate technological unit
RAH	= RAF from the hotter building space
RAC	= RAF from the colder building space
RHE	= Recovery heat exchanger
TC	= Thermal comfort
TU	= Technological unit