HEAT RECOVERY DEVICE IN AIR-CONDITIONING SYSTEMS: REAL COST SAVER OR UNNECESSARY INVESTMENT

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ABSTRACT

Nowa days an air conditioning design engineer is faced with a challenging task to minimize energy consumption and capital costs. One of the most common solutions is to apply heat recovery device. However, simple application of heat recovery device may not always produce energy cost savings. Sometimes investment costs may overcome energy savings, and feed-back period may be longer than equipment lifetime.

Usually, the conditions in which use of heat recovery device, in the air-conditioning systems, is economical, is not strictly and clearly defined. In this paper the appliance of heat recovery devices is discussed due to its economical approvement depending on the airflow, outside and inside air parameters, air conditioning system regime etc.

From the stand point of the design engineer, it is very important to define all parameters and their values which can influence possible choice how to apply heat recovery device . Those parameters concern above mentioned data.

The analyses procedure and algorithm that has been made in this paper cover is trying to define outside and inside air parameters which justify appliance of heat recovery device.

Special attention has been made to feed back period as well to the regime of heat recovery device.

This paper, also, summarizes all necessary things that an design engineer should consider before he decides to apply some heat recovery device in order to achieve energy cost savings.

1. Air conditioning plant configuration

A properly applied heat recovery device, in a air conditioning plant, should increase investment cost insignificantly, especially in a big project, at the same time providing long term benefits through reduced energy consumption. This equipment reduces size not only of heating and cooling coils but support utility equipment (boilers, chillers.) as well. Heat recovery devices are usually placed between outdoor air intake and the coils. In the case of mild climates or in the transient period they may replace the preheating coils.

As the exhaust air temperature is higher than the supply air temperature the percentage of saved energy increases. Higher temperature difference between two air streams is more economical than energy recover of low temperature difference systems.

1.1 About the Units and Physical Aspects of the Process

1.1.1 Rotary Heat Exchanger

The first preference should be given to a rotary heat exchanger, especially for comfort ventilation, since it has the best efficiency, the most reliable method of control, and can recover moisture from the space.

Rotary heat exchanger, may be selected to recover only sensible heat, or both sensible and latent heat. Non-hygroscopic exchanger is cheaper, but hygroscopic exchanger makes less operating costs. General rule is that in smaller systems where energy consumption is not so important, the first preference should be given to the non-hygroscopic exchanger. In larger systems hygroscopic exchanger are preferable.

The cross contamination of air between supply and exhaust air streams occurs in all rotary heat exchanger through carry over and leakage. Leakage can be reduced by the appropriate fan arrangement.

If the exhaust air contains water soluble odors substances, condensation will cause the odor to be transferred from the exhaust air to the supply air specially in the case of hygroscopic rotor. Because of the risk of transfer of smells and bacteria, this heat exchanger, cannot be used in dwellings, operating theater's, public baths etc.

1.1.2 Liquid Coupled Heat Exchanger

Liquid coupled heat exchanger has the lowest energy efficiency of all heat recovery devices.

Liquid coupled heat exchangers are used:

- in systems in which no leakage whatever, and no transfer of odors between exhaust and supply air is permissible,
- for systems that involve remote air streams and/or complicated ducting such as in the HVAC system of large buildings,
- instead of the rotary heat exchanger when exhaust air temperature is high,
- in the systems with remote location of supply and exhaust ducts,
- in the systems with simultaneous recovery of energy from multiple supply and exhaust duct (central heat recovery).

First step in applying heat recovery device is to compose heat recovery device into air conditioning plant carefully, to reduce fan operating costs. A few recommendations should be followed

1.2 Possible Heat Exchanger Arrangement That Design Engineer Should Think Of

The leakage of return air into the supply air in the rotary heat exchanger unit can be eliminated with proper position of fans and air dampers. The pressure difference between supply and return air ducts on both side of rotary heat exchanger should be such that $p_2 > p_3$ and $p_1 > p_4$, what could be achieved by installing a pressure-adjusting damper, Figure 1a and 1b. Also, it is necessary to ensure that the total air pressure difference in return and supply air duct is as small as possible in order to minimize leakage across the seals. The leakage across the seals is normally 1 - 4% of total air flow. If it is possible, rotary heat exchanger should be on inlet side of fans, Figure 1a and 1d. To enable proper function of mixing box, during start up regime, fans should be positioned so that $p_6 > p_5$. The installation of mixing box after rotary heat exchanger Figure 1c, enables air handling plant to have the smallest dimension, however this construction causes significant leakage of return air into supply air, usually about 15% of the amount of return air. Reduction of air handling plant dimension can be, in some cases, more important than the decrease of air pressure drop in system. During start up period air flow is usually reduced to approximately 30% of the original supply air flow.

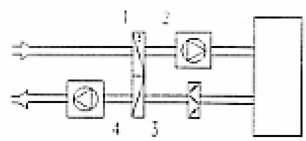


Figure 1a.

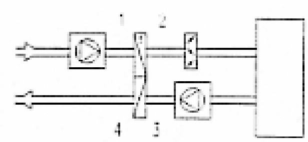


Figure 1b

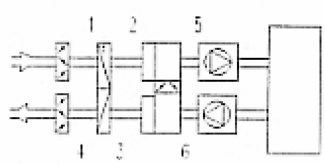


Figure 1c

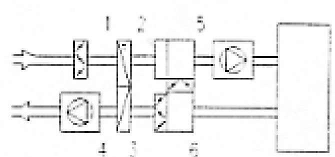


Figure 1d

Figure 1. *Possible Fan and Mixing Chamber Arrangement in Conjunction with Rotary Heat Exchanger*

Special construction of liquid coupled heat exchanger could be applied in the system working mostly in summer regime and only for those spaces in which maximum humidity is limited, Figure 2. In this case both exchanger are located in supply air duct and one coil has function of "precooling" and other of "reheating" coil. "Precooling" coil should be positioned after heating coil. This arrangement of liquid coupled heat exchanger can be used in conjunction with the other heat recovery devices i.e. mixing box and rotary and plate heat exchanger, Figure 2. Since this arrangement significantly increases fan energy it should be used only when liquid coupled heat exchanger efficiency allows reheat function.

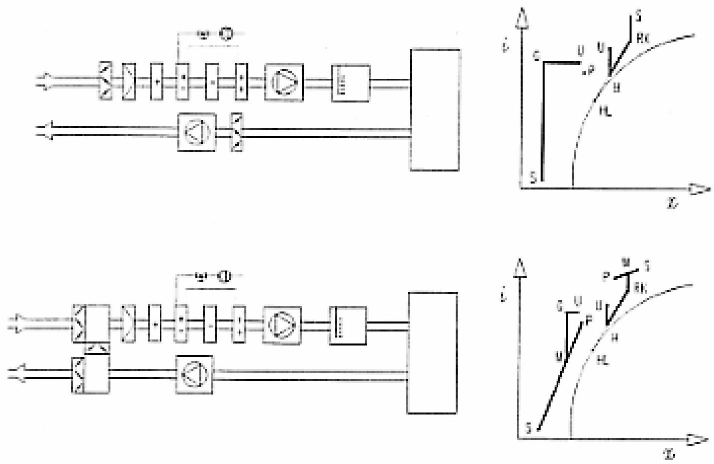


Figure 2. *Air Handling Plant with Special Construction of Liquid Coupled Heat Exchanger without and with extra heat exchanger*

2. Thermodynamics Bases And Calculations In The Analyses Of Heat Recovery Device Application

To make some analyses of operating costs, the design engineers should take into account average temperatures and hymidities. This should be calculated by one of shorter methods that can provide correct precision, does not require large calculation procedures and is not big time consumer. Because in design process there is always lack of available time for this kind of calculations.

The initial cost of particular heat recovery device including additional ductwork, piping, filtration equipment and auxiliary heaters for frost control should be considered together with periodic cost for the maintenance of heat recovery device and associated equipment. Opposite to that, possible savings are due to the reduced size of boilers and heating equipment together with chillers and cooling equipment with associated coils, piping, etc., plus periodic savings due to the reduced energy consumption in the heating and cooling season.

In making his own decision in applying heat recovery device the design engineer should take following steps.

1. The first step for design engineer is to analyze system configuration. Does this system have the possibility to apply heat recovery device at all. e.g. the system is with remote location of supply and exhaust system so that even liquid coupled heat exchanger can not be connected.

2. Define the time of system operation and total heat gains and cooling loads for each system as well as their air flow, define inside air parameters for winter and summer regime. Define all average month air temperatures and hymidities and put it in the moist air chart. Those data will be of great help later, and they are more relevant information in considering periods of heat recovery device operation than outside air design parameters.

3. Make necessary air handling system configuration due to the outside and inside air parameters.

4. Make choice in selecting between rotary and liquid coupled heat recovery device. At this point we should notice that rotary heat exchanger has much more limitations in use than liquid coupled exchanger, and, that rotary heat exchanger has better efficiency but it is not necessary cheaper. In selecting heat recovery device design engineer should refer to the all above mentioned.

5. If we are selecting rotary heat exchanger now we have to decide between hygroscopic or non hygroscopic. The choice is very simple if we do not have room air humidity maintenance, then non hygroscopic device always should be applied except in the case that were mentioned in the chapter 1.1.
A more complicated case is when we have humidity maintain during winter or summer or in both regimes. To make this analysis we have to use average outside air parameters. If air humidification is obtained in water-spray humidifier installation of hygroscopic rotary heat exchanger is strongly recommended because it can significantly reduce the amount of energy required for preheating coil.
In the case of using steam humidification, it is certain that hygroscopic device provide decrease of humidifier energy consumption. Except when supply air has to be less humid than room air due to the demand of specific process or number of people in room. Fig. 3

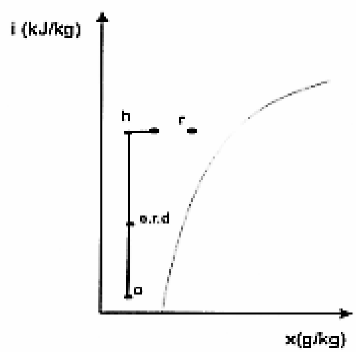


Fig. 3 *Low moisture ratio of supply air*

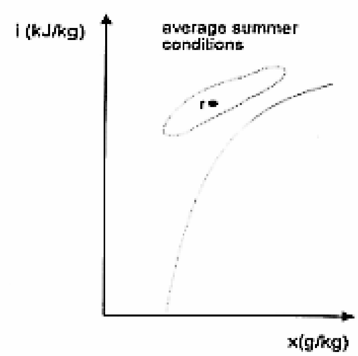


Fig. 4. *Average summer air parameters*

We should also focused on summer regime, if there is one, to make our choice. Our choice will be hygroscopic heat exchanger if temperature difference between outside and inside parameter is much smaller than the air humidity difference Fig 4 what is case in most European countries.

6. At this point we may finish our analyze. Now we should check investment costs. That means that we should sized our primary equipment, boilers, chilers, and fans, as well as additional equipment like extra heat exchanger. If this calculation shows significant difference in investment costs it is very likely that will end our analyze. This can be fairly accurate especially for cold or hot climate. In the case of minor difference in investment costs or in the case of mild climate e.g. small temperature difference we should continue calculation.

All above mentioned steps were preparation for the following procedure.

7. First we should consult the manufacturer about heat recovery device effectiveness related to the various temperature differences between supply and exhaust air streams and for the selected air flow e.g. air velocity. We should take into account that decrease of temperature difference also decreases recovery efficiency.

8. Then all additional power consumer should be indentified and sized, e.g. power consumption of pump for liquid coupled exchanger or rotary exchangers motor.

9. Calculation of pressure drop into air duct and air handling units with and without selected heat recovery device incorporated in air plant. Also we should selected the cold and hot water pumps for both cases.

10. The next step is to calculate what real energy savings outside air temperatures can give. Connecting those temperatures with average months air parameters we can recognize all possible periods of year in which heat recovery device will consume more energy than it can save by applying next equations.

$$Q_{sav} = \rho c_p \dot{V} \sum_{i=1}^{n} (i_o - i_r) \eta_{\Delta i} \quad \text{- for hygroscopic exchanger} \qquad (1)$$

$$Q_{sav} = \rho c_p \dot{V} \sum_{i=1}^{n} (t_o - t_r) \eta_{\Delta t} \quad \text{- for liquid coupled and non hygroscopic device} \qquad (2)$$

where:

Q_{sav} - saved energy in the heat recovery device (W)
ρ - specific air density (kg/m^3) c_p- specific heat (kJ/kgK)
n - number of months of system operation $\dot{V}$ - air volume (m^3)
i_o - average month outside air enthalpy (kJ/kg) i_o - exhaust air enthalpy (kJ/kg)
t_o - average months outside air temperature (^{o}C) t_o - exhaust air temperature (^{o}C)
$\eta_{\Delta t}$ - heat recovery device efficiency for selected outside and exhaust air parameters

Also we should calculate energy savings for steam preparation in the case of steam humidification and hygroscopic heat exchanger

$$Q_{humsav.} = \rho c_p \Delta t_w L_s \sum_{i=1}^{n} \Delta x \, \eta_x \qquad (3)$$

where:

$Q_{sav\,hum}$ - is energy saved for humidification (W)
Δt_w - is temperature difference between steam and water (^{o}C)
L_s - steam flow (m^3/h)
Δx - difference between average outside and inside humidity for selected months (g/kg)
η_x - rate of moist transfer

11. By knowing all data which are found in paragraphs 7. and 10. we can now define periods in which energy savings overcome additional energy loss in order to define periods of heat recovery device operation. This can be seen on Fig. 5

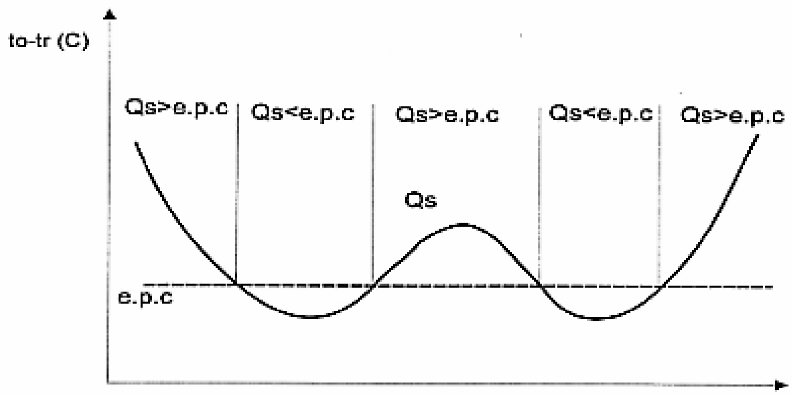


Fig. 5. *(Qs) Saved energy and (e.p.c) extra power consumption*

Period in which extra power consumption during one year can happen as it can be seen on Fig 5. Periods when extra power consumption during utilization of heat recovery device overcome energy savings may happen in transitional periods of year. It is assumed that power consumption of recovery devices is constant, which is fairly accurate for this type of analyses. Of course, for giving correct calculations we should analyze structure and prices of all energy sources which are incorporated in this analyze

12. Former data can give us a picture of energy saving periods. These data are related only to the amount of energy that is saved. The next thing is to relate these data to the energy prices. The whole process which is connected to cooling as well as all extra power consumption, increase of fan power due to the increase of pressure drop in the system strictly depends on electrical energy. On the contrary all heating process can be provided by using different energy sources from district heating, gas to the electrical energy as well. To calculate difference in operating costs during one year we should take into account all mayor parameters which can influence energy consumption incorporating average month parameters.
In this part of our analyze we should focus only on the air plant energy consumer whose power will change due to the appliance of the heat recovery device. Those parts whose energy consumption remain unchanged will not be discussed. In the case of the air conditioning system relevant parameters are heating and cooling equipment, humidifyer, hot and cold water pumps, fan and heat recovery device.
First we should calculate annual operating costs without any heat recovery device.

$$E_{an} = Q_h \cdot t_h \cdot P_h + (Q_c \cdot t_c + Q_w \cdot t_w + H_{fan} \cdot t_f + H_{hp} \cdot t_{hp} + H_{cp} \cdot t_{cp}) \cdot P_{el} \quad (\$) \qquad (4)$$

where:
E_{an} - annual energy costs ($)
t_h - annual operation of heating equipment (h) P_h - specific heating costs ($/ kWh)
Q_h - amount of energy for heating for average months conditions (kW)

This equation is correct for electric or district heating. In the case of individual heating by gas, petrol or coal, this part of equation should look like this:

$$Q_h \cdot t_h = C_F \cdot m \cdot \eta_{hs} \quad (kW/h)$$

C_f - specific heat of used fuel (kJ/kg; kJ/m^3)
m - annual fuel amount (kg; m^3)
η_s - system efficiency

Q_w - amount of electric energy for cooling for average months temperature (kW)
t_w - annual chiller operating time (h)

Q_w - amount of energy for humidification for average months humidity (kW)
t_w - annual humidifier operating time (h)
This is only applying for the steam humidification and it can be neglected in the case of spray humidification.

H_f - fan power, both supply and exhaust (kW)
t_f - annual time of fan operation (h)
H_{hp} - hot water pump power (kW)
t_f-annual time of pump operation (h)
H_{cp} - cold water pump power (kW)
t_f-annual time of pump operation (h)

P_{el} - specific electric power costs ($/ kWh)

The same equation can be written for the case of appliance of heat recovery device

$$E`_{an} = Q`_h \cdot t`_h \cdot P_h + (Q`_c \cdot t`_c + Q.`_w t`_w + H`_{fan} \cdot t`_f + H`_{hp} \cdot t`_{hp} + H`_{cp} \cdot t`_{cp} + e.p.c \cdot t_{epc}) \cdot P_{elf} \quad (\$) \qquad (5)$$

where
e.p.c - additional heat recovery device pumps, motors and etc. (kW)
t_{epc} - annual time of operation (h)

It is very important to notice that all values in this equation differs from the above equation (that is why they have superscript `) but they are also based on the average months data.

12. Now when we have all those investment costs as well as annual operating costs we can find three characteristic situation:

A) If investment and operating costs with heat recovery device are smaller than without heat recovery device, energy savings certainly should be applied, Fig 6

B) If investment costs with heat recovery device are lower, due to the reduction of equipment size and operating costs are higher due to the high electric power price; we might apply energy savings depending on feed-back period, Fig. 7. It is more favorable to have longer feed-back period.

C) Investment costs with heat recovery device can be higher, inspite slight reduction of equipment because of extra costs due to the additional ductwork, piping.... We might apply energy savings if operating costs decrease, Fig. 8. More favorable case is to have shorter feed-back period.

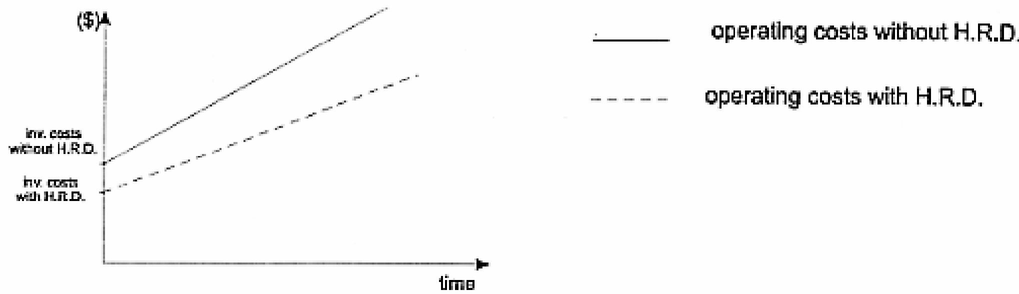


Fig. 6

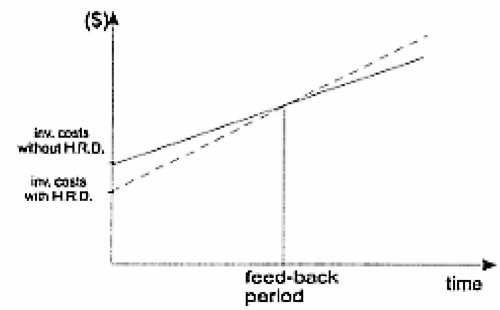


Fig. 7

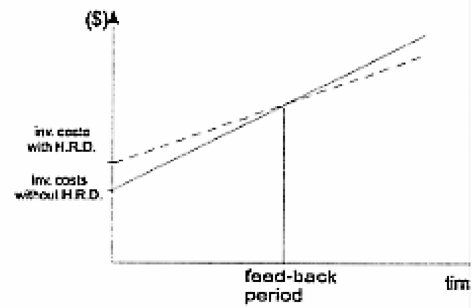


Fig. 8

3. Conclusion

The selection of the heat recovery device type depends on the factors such as device effectiveness, space requirements, leakage protection, and investment maintenance and operating costs. It is not possible to make a general comparison of the cost of different alternatives, i.e. in regions with high electric costs heat recovery device, with low pressure drops is preferable in order to save fan required energy. Therefore, the annual cost for different alternatives has to be considered individually for each plant.

As we can see this analyze was very quick and it has many assumptions. Of course, a more detailed analyze can be done by using more detailed meteorological data, by more precise calculation of all investment costs (additional piping, ducting, reduction of pump sizes ..) and incorporating maintenance costs. This kind of calculation is big time consumer.

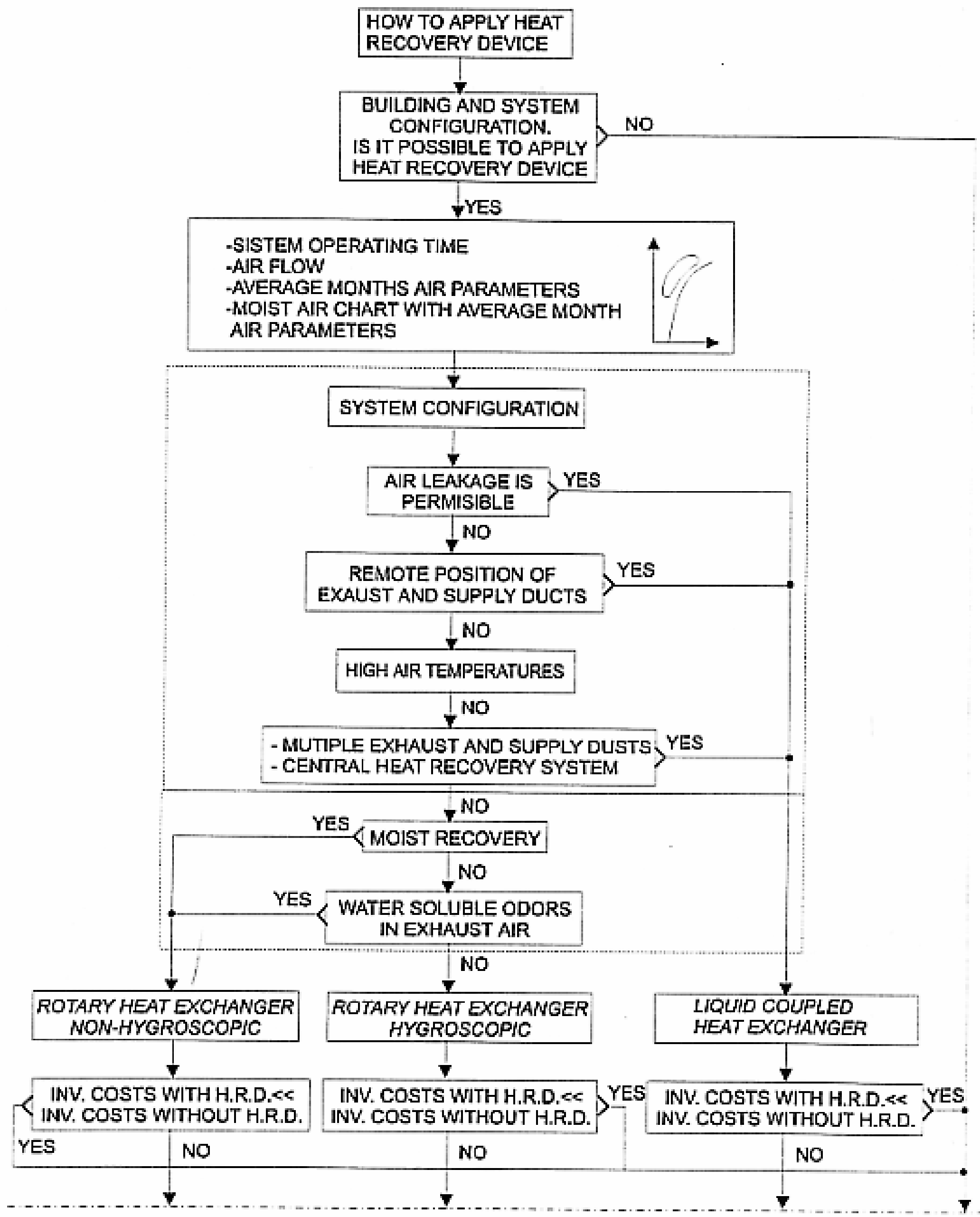
As product of this analyze we can extract two characteristic cases which may, at first look, confuse design engineers and lead them to the wrong conclusion.

It is possible that, because of high electrical costs, operating costs with energy saver are higher in many periods of year. But in the conjunction with lower investment costs long feed back period justifies applying of heat recovery device.

On the other hand, it is possible that the investment costs incorporating heat recovery device may be higher and that the operating costs do not differ significantly due to the cheap electrical energy so that feed back period can be so long to overcome equipment lifetime. In that case we certainly will not use heat recovery device.

As we can see in order to make a real judgment of economical aspect in applying heat recovery device we have to consider all above mentioned facts. It is not always necessary that heat recovery device has to provide decrease of both investment and operating costs. Therefore this kind of analyze and the way thinking is the basis of properly energy savings and way to avoid unnecessary costs

All things that we mentioned above we can show in following algorithm.


HOW TO APPLY HEAT RECOVERY DEVICE
BUILDING AND SYSTEM CONFIGURATION. IS IT POSSIBLE TO APPLY HEAT RECOVERY DEVICE
NO
YES
-SISTEM OPERATING TIME
-AIR FLOW
-AVERAGE MONTHS AIR PARAMETERS
-MOIST AIR CHART WITH AVERAGE MONTH AIR PARAMETERS
SYSTEM CONFIGURATION
AIR LEAKAGE IS PERMISIBLE
YES
NO
REMOTE POSITION OF EXAUST AND SUPPLY DUCTS
YES
NO
HIGH AIR TEMPERATURES
NO
- MUTIPLE EXHAUST AND SUPPLY DUSTS
- CENTRAL HEAT RECOVERY SYSTEM
YES
NO
MOIST RECOVERY
YES
NO
WATER SOLUBLE ODORS IN EXHAUST AIR
YES
NO
ROTARY HEAT EXCHANGER NON-HYGROSCOPIC
ROTARY HEAT EXCHANGER HYGROSCOPIC
LIQUID COUPLED HEAT EXCHANGER
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INV. COSTS WITH H.R.D.<< INV. COSTS WITHOUT H.R.D.
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YES
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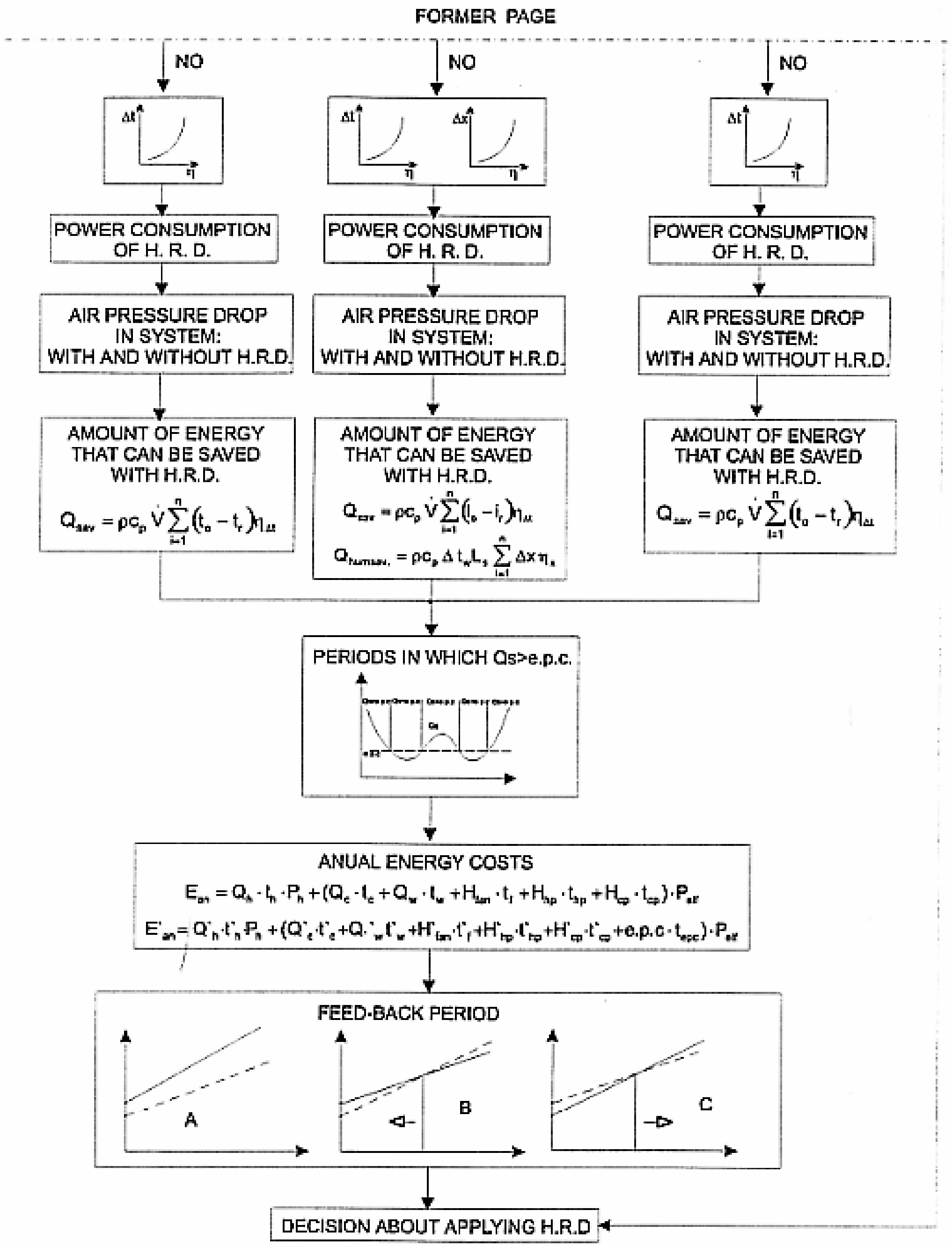
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Q_humsav. = ρc_p Δt_w L_s Σ_{i=1}^{n} Δx η_x
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Q_sav = ρc_p V̇ Σ_{i=1}^{n} (t_o − t_r) η_Δt
PERIODS IN WHICH Qs>e.p.c.
Qs
ANUAL ENERGY COSTS
E_an = Q_h · t_h · P_h + (Q_c · t_c + Q_w · t_w + H_fan · t_f + H_hp · t_hp + H_cp · t_cp) · P_el
E'_an = Q'_h · t'_h · P_h + (Q'_c · t'_c + Q'_w · t'_w + H'_fan · t'_f + H'_hp · t'_hp + H'_cp · t'_cp + e.p.c · t_epc) · P_el
FEED-BACK PERIOD
A
B
C
DECISION ABOUT APPLYING H.R.D