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APPLICATION OF HEAT RECOVERY IN OUTDOOR AIR FOR OFFICE BUILDINGS IN BRAZILIAN CITIES

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S2 - Componentes e Equipamentos de Tratamento de Ar

Abstract. *This paper demonstrates the application of heat recovery in office buildings in Brazilian cities and analyzes the heat gains due to the outdoor air intake for each city, as well as the different types of heat recovery. The results show that in annual energy saving is possible and that enthalpy recovery presents better gains than sensible recovery in tropical regions. Energy saving ranging from 2% to 12% is obtained depending on the climate conditions.*

Keywords: *HVAC Systems, Exhaust Air Heat Recovery, Brazilian Cities*

1. INTRODUCTION

Since the 1970s, there has been a global movement for energy conservation and this idea has been applied to projects comprehensively. This led buildings to reduce outside air exchanges to a minimum in order to reduce the thermal load, which made the concentration of pollutants inside buildings reach high levels (Nascimento, 2011). This also led the WHO (World Health Organization) to consider the inside pollutants in buildings one of the main environmental problems for public health. About half of the population is estimated to suffer from the poor quality of indoor environments (Bruce et al., 2000). Therefore, in the late 1970s, studies on the quality of indoor air were started. In Brazil, these studies started in the 1990s (Nascimento, 2011) and settled a minimum level of outdoor air inflow in buildings by elaborating standards, such as ABNT NBR 16401 and ANVISA.

However, the required outdoor air flows represent 20% to 40% of the consumption of an HVAC system (Rosouli et al., 2013), which affects the reduction of energy demand in buildings. This increased the use of efficient strategies able to recover energy from the exhaust air (Mardiana-Idayu and Riffat, 2011).

Heat recoveries are effective in increasing energy efficiency in buildings due to the precooling of outdoor air and to the reduction of the thermal load. Heat recoveries can also reduce the size of the equipment in the HVAC system (Rosouli et al., 2013). However, the performance in reducing energy consumption and, consequently, in reducing the costs, has been the main reason for using this equipment.

Research has demonstrated the energy and economic gains. Mardiana-Idayu and Riffat (2011) studied a small prototype in laboratory using an enthalpy plate heat recovery and observed changes in the efficiency of heat recovery as a function of air velocity, wherein the higher the velocity, the lower the efficiency in heat recovery.

Rosouli et al. (2010) studied latent and sensible heat recoveries. Different ranges of efficiency and different controls were analyzed. His studies were conducted in four difference cities in the USA and showed reductions in the consumption by 40% in the heating system in winter and by 20% in the cooling system in summer. In another study in the city of Chicago, Rosouli et all. (2013) analyzed how the variation in the sensible and latent efficiencies affects the size of the equipment, the energy consumption and the time for the investment payback. He obtained 20% reductions in the size of the chiller and 40% in the boiler. In addition, the annual energy consumption was reduced by 8% for cooling and by 40% for heating, and a payback of 2 years was obtained.

Wallin and Claesson (2014) studied a system with heat recovery and heat pumps in Sweden, and obtained a 63% heat recovery in the annual energy; this gain was practically obtained in the winter period.

Zhong et al., (2012) studied the weather in four different Chinese cities and analyzed how the enthalpy heat recoveries provided gains for each city. He obtained gains between 42% and 56.6 % in winter for colder cities and gains between 51.6 and 52.1% in summer. Also in China, Ke and Yanming (2009) carried out a study in many types of heat recoveries in eight Chinese cities, recovering energy both in winter and in summer. He analyzed how the efficiency in energy recoveries was affected by the local weather in each city and obtained greater gains in cities with colder weather.

Zhang and Niu (2001) studied a membrane heat recovery in the city of Hong Kong, which has subtropical weather. He obtained a 58% energy recovery in the exhaust air and 12.4 % economy in the annual cooling consumption .

The works aforementioned demonstrate that heat recoveries provide economy for buildings. However, this economy is linked to many factors, such as the operation, the HVAC system, the efficiency of the heat recovery and the local weather. These researches were limited to some kinds of weather. To our knowledge, there is no research for tropical weather, which is the weather in Brazil. Therefore, this paper aims to present a study on heat recoveries in four Brazilian cities, analyzing different recoveries, both sensible and latent, and to present the economy provided by heat recoveries.

2. BUILDING MODELING

EnergyPlus™ is a software developed by the US Department of Energy with the capacity of running energy simulation. This software has the capability of simulating plants and integrating systems, for example, it simulates plants of heating, cooling and ventilation and it integrates these plants to simulate the whole HVAC system. Besides that, this software can calculate the consumption of the light system, equipment system and other systems necessary to simulate the whole building consumption.

2.1 Description of the building

The building chosen for this study is a standard Brazilian twenty-two-floor office building of rectangular geometry. The elevators, restrooms, corridors, and stairs are in the center of the floor, while the office areas are on the perimeter, next to the windows. Its layout and geometry can be seen in Figure 1. The building was modeled using the standard ASHRAE 90.1-2007, Brazilian standard NBR 16401-2008, and ANVISA, using the following parameters:

- Building envelope: the model follows Chapter 5 from the ASHRAE 90.1-2007 standard.
- Light system: the model follows Chapter 9 in the ASHRAE 90.1-2007 standard.
- Density for occupation and equipment: the model follows the high occupancy of Table C.6 from NBR 16401-2008.
- Schedule of operation: the building operates between 07:00 and 20:00 on weekdays, between 08:00 and 14:00 on Saturdays and does not operate on Sundays. The schedule is presented in Figure 2.

2.2 Air conditioning system

The design conditions to maintain occupants' comfort adopted for this work was the Brazilian standard, the thermostat was controlled at 24°C and relative humidity at 50% for conditioning inside the thermal zone. As in Brazil controllers for humidity are not installed in office buildings, to keep the relative humidity around 50%, the system is designed with 12.8°C in the outlet of the cooling coil, which keeps the relative humidity around 50% when the supply air reaches 24°C within the thermal zone. The air cooling system was modeled according to appendix G of ASHRAE 90.1-2007; therefore, the air conditioning system follows Table 1.

2.3 Outdoor air intake rates

The outdoor air intake rate was designed by analyzing three standards, ASHRAE 62.1-2004, NBR 16401-3-2008 and ANVISA. The highest flow required for density occupancy for this building was ANVISA, 27 m^3/h/people. Therefore, to conform with the three standards, ANVISA was used in the simulations.

Table 1. Summary of air condition system, based on ASHRAE 90.1-2007.

Air conditioning system		
Chilled water system with two water cooled electric chiller with compressor centrifugal, the cooling tower has axial fans with two-speed fans, the primary system with constant pumps and the secondary system with variable speed drives, the condenser pumps were interlocked to operate with the associated chiller. The distribution of air by VAV's (volume air variable).		
System components	**Parameter**	**Characteristic of the system**
Building peak cooling load	Peak load ≥ 600 TR	COP = 6,10 W/W and IPLV = 6,4 W/W (Condition ARI 550/590)
Chilled water pumps	349 kW/1000 L/s	Primary system with constant flow and secondary system with variable flow Reset for temperature based on outdoor dry bulb temperature: 6.7°C at 27°C, 12°C at 16°C and below ramped linearly between 6.7°C and 12°C.
Condenser water pumps	310 kW/1000 L/s	Design supply temperature for 29°C, but the tower shall be controlled to maintain 21°C leaving water temperature where weather permits.
Cooling tower	≥ 3,23 L/s.kW	Axial fan with two-speed fans
Fan-coils	Variable Air Volume (VAV)	Supply air system design in 12.8°C (11.2°C lower 24°C)

Obs: 1) COP: coefficient of performance [dimensionless]; 2) IPLV: integrated part load value [dimensionless]

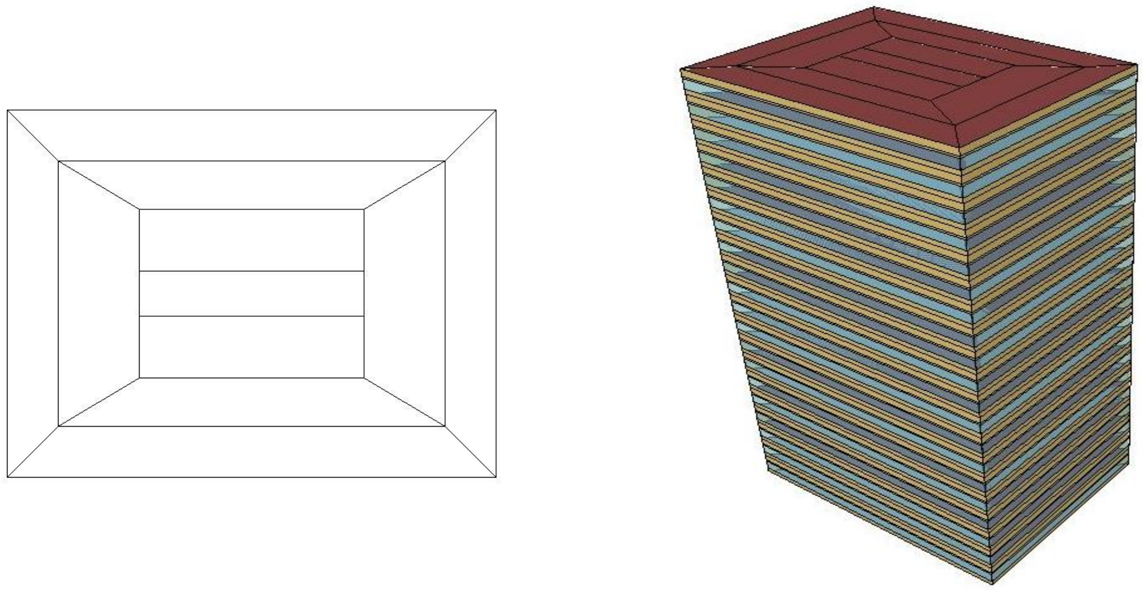

Figure 1. Layout and geometry of the building studied.

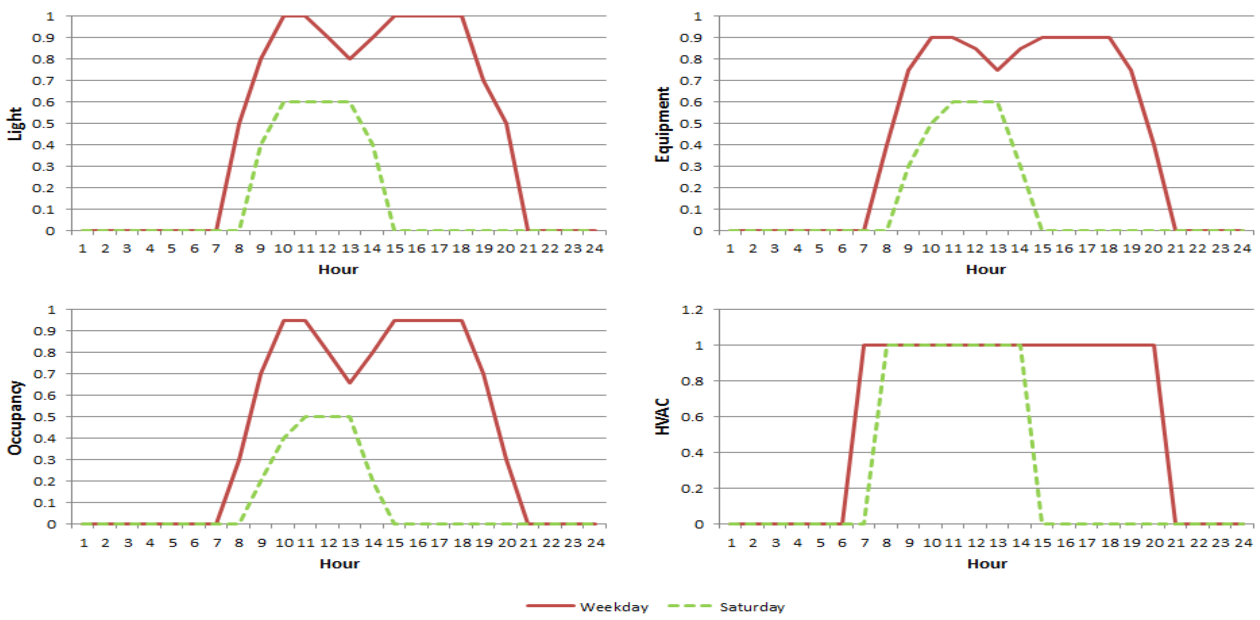

Figure 2. Schedule for each type of use in the building.

3. BUILDING MODELING

The purpose of the heat recovery equipment is to recover the energy of the exhaust air of the building, which is near the inside comfort conditions, to pre-conditioner the outdoor air, which has high temperature and high humidity. This way it reduces the energy spent in cooling this outdoor air, which is necessary to keep the quality inside the office within minimum standards. The operation of the heat recovery system is demonstrated in Figure 3. The input of outdoor airflow crosses the output of the exhaust airflow, promoting the sensible heat exchange by use of the conductive material and the latent heat exchange by use of the ceramic materials, which allow the humidity flow.

There are two options to control the heat recovery, either by temperature or by enthalpy. Whenever the sensor indicates an economic advantage in carrying out the exchange, the flow goes through the heat recovery, when the sensor does not indicate advantage the flow is interrupted and displaced to bypass. Thus, when the outdoor conditions are low temperature and low humidity, the outdoor air is not heated.

In the current Brazilian market, there are two types of heat recoveries employed in office buildings:

- Rotary recovery: enthalpy recoveries.
- Plate recovery: can involve sensible recovery or/and enthalpy recoveries.

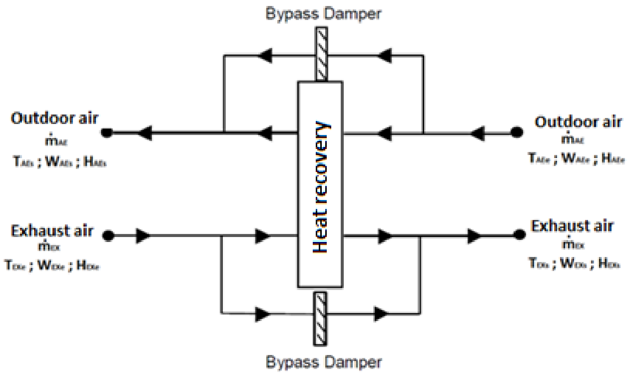

Figure 3. Schematic of the heat recovery system (HRS)

Each system has its advantages and disadvantages, and designers must choose the best for their projects. In the case of rotary recoveries, the efficiency is higher, yet these recoveries allow leaks between exhaust air flow and outdoor air flow, which is not the case of plate recovery.

The efficiencies in exchange are obtained by Equations (1), (2) and (3). Table 2 presents the efficiencies found in the Brazilian market for each type of heat recovery.

Sensible efficiency: $$\varepsilon_S = \frac{T_{AEe} - T_{AEs}}{T_{AEe} - T_{EXe}} \quad (1)$$

Latent efficiency (only for enthalpy recovery): $$\varepsilon_L = \frac{\omega_{AEe} - \omega_{AEs}}{\omega_{AEe} - \omega_{EXe}} \quad (2)$$

Enthalpy efficiency (total efficiency): $$\varepsilon_{tot} = \frac{H_{AEe} - H_{AEs}}{H_{AEe} - H_{EXe}} \quad (3)$$

In Equations (1) to (3), ε is the efficiency of heat recovery (dimensionless), T is the temperature (ºC), ω is the absolute humidity (kg vapor/kg dry air), and H is the enthalpy (kJ/kg). Subscripts S, L, tot, AEe, AEs, and EXe are respectively sensible, latent, total, outdoor air at HRS inlet, outdoor air at HRS outlet, and exhaust air at HRS inlet.

Table 2. Sensible and latent efficiency for each type of recovery.

Efficiency	Heat recovery		
	Rotary	Plate	
	Enthalpy	Enthalpy	sensible
Sensible efficiency	0.8	0.756	0.756
Latent efficiency	0.78	0.62	0

4. CLIMATIC CONDITIONS

Our study presents the gains obtained in the main Brazilian cities, and the two largest cities in Brazil are analyzed, São Paulo and Rio de Janeiro. A city from the northeast was analyzed, too. To represent the climatic conditions in the cities of the northeast, Recife was chosen. The capital of Brazil, Brasilia, was analyzed, too, to represent the climatic conditions in the Mid-West.

The cities in the south were not analyzed because their weather is cooler, they do not have great gains in the energy recovery of exhaust air.

The weather files used in these analyses were developed by Roriz (2012), who elaborated the weather file using data from INMET between 2000 and 2010. Because this file uses recently collected data, these weather files were used as a base for this paper.

4.1 Heat gains from outdoor air

The heat gains are obtained by equations (4), (5) and (6):

Sensible heat gain: $$\dot{Q}_S = \dot{m} c_p \Delta T \quad (4)$$

Latent heat gains: $\dot{Q}_L = \dot{m} L \Delta\omega$ (5)

Total heat gains: $\dot{Q}_{tot} = \dot{m}\Delta H$ (6)

where $\dot{Q}$ is the heat gain (W), $\dot{m}$ is the mass flow rate (kg/s), and c_p is the specific heat (kJ/kg.°C). Using the weather file for each city (outdoor air condition), the design condition (24°C and 50% relative humidity) and equations (4) (5) and (6), the gains referring to the entry of outdoor air were obtained. These gains are presented in Fig. 4, which shows that, for Brazilian cities, the highest energy expenditures for cooling outdoor air concern the energy spent to dehumidify the air. Another aspect that can be seen in Fig. 4 is that cities, such as Rio de Janeiro and Recife, present greater gains for outdoor air because these cities have high temperatures and high humidity over most of the year, differently from cities such as São Paulo and Brasilia.

5. RESULTS

5.1 Energy recovery in each type of heat recovery

From an 8760-hour annual simulation, the energy savings for each type of heat recovery were obtained and are presented in Fig. 5.

The energy saving from sensible recovery is lower than the energy saving from latent recovery. This was expected because of the high humidity in tropical weather. See Fig. 4, which presents high latent heat gains in outdoor air. Because of the lower performance of sensible recovery, only the two types of latent recoveries were analyzed and compared, rotary latent heat recovery and plate heat latent recovery.

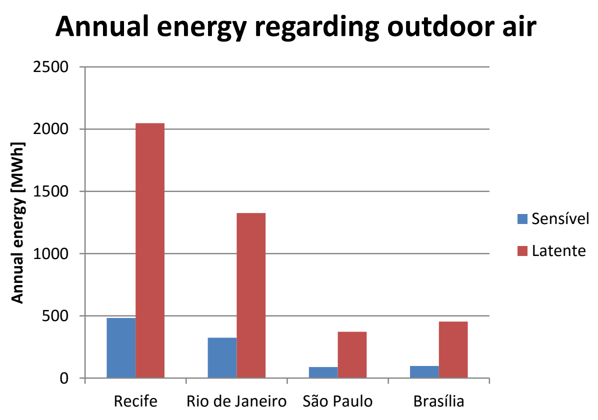

Figure 4. Annual energy regarding outdoor air.

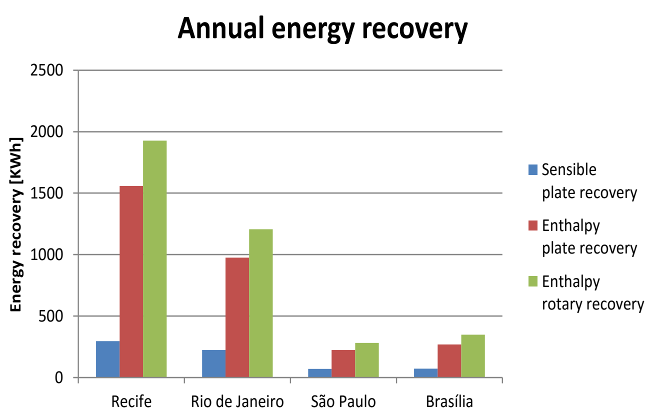

Figure 5. Energy saving for each type of heat recovery.

5.2 Consumptions

Figure 6 shows the consumptions in air conditioner systems separated for each type of use in the HVAC system: chiller, fans, pumps and cooling tower. Such figure depicts the difference in the consumption of air conditioning systems for each city. Recife presented the highest consumption in the HVAC system and São Paulo is the city with the lowest consumption in the HVAC system. It is observed a reduction in the chiller, pumps and tower consumption, but it is observed an increase in fan consumption. This increase in fan consumption occurs because of the increase of pressure drop caused by heat recovery. The pressure drop is an important subject in heat recovery studies, because if the local weather does not provide great gain in the chiller, pumps and tower consumption in warm periods, it is possible that the increase in fan consumption might bring a loss for the building consumption. Therefore, it is important to conduct annual studies when heat recovery is to be used as strategy.

5.3 Percentile saving

Figure 7 presents the percentage of reduction in the HVAC system. The gains are greater for Recife and Rio de Janeiro due to high temperature and high humidity, which allow that the heat recovery operates along most of the year. To obtain the economic gain of the heat recovery in the building, the electric tariff was inserted in the simulation according to the website of each electric company, whose values are presented in Table 3.

The cost savings obtained are presented in Fig 8. Cities, such as Recife and Rio de Janeiro, have the highest cost savings, making the payback time shorter. Therefore, for cities such as São Paulo and Brasilia, the payback should be analyzed to see whether it is acceptable for the building.

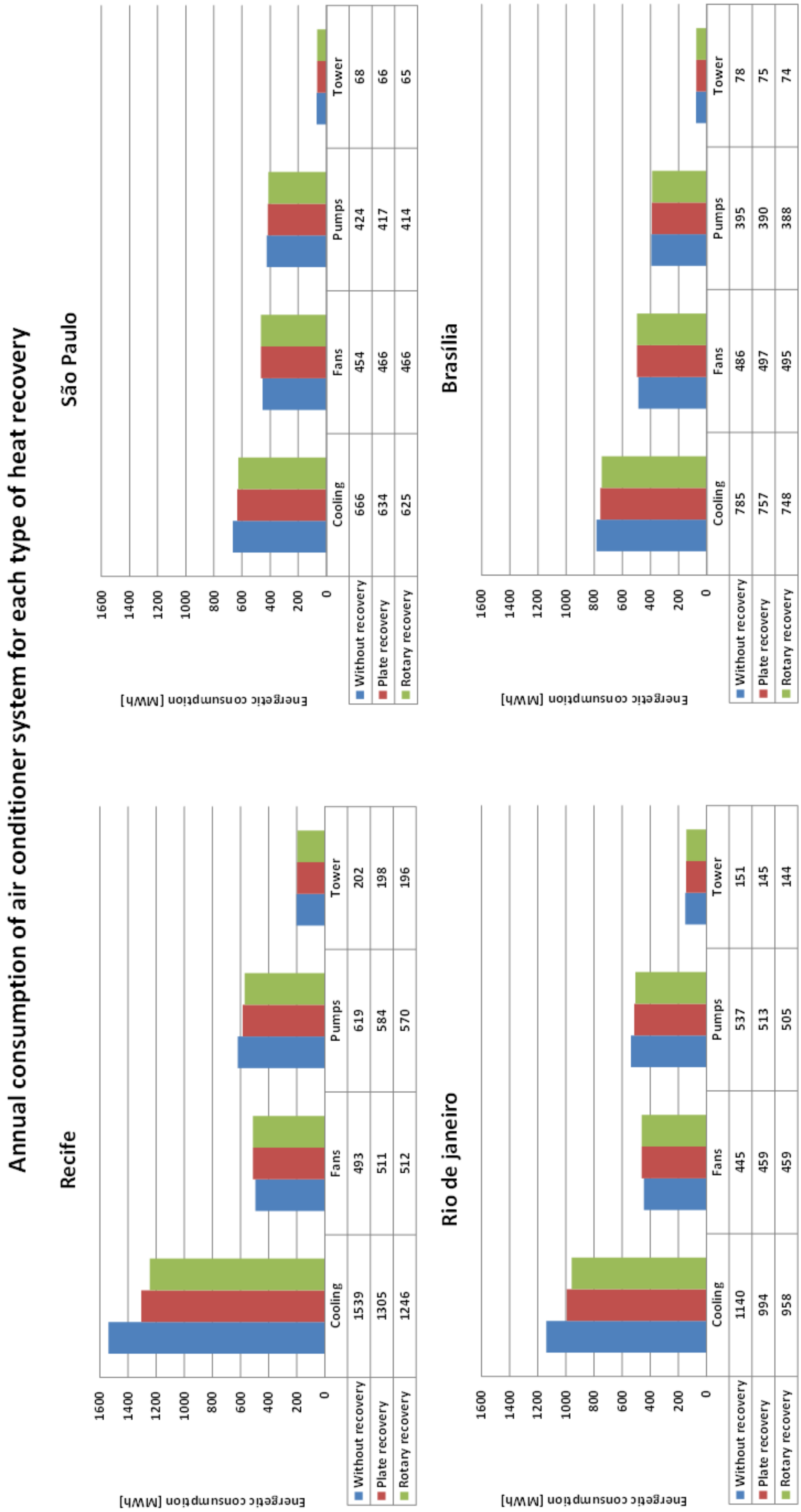

Figure 6. Annual energy consumption of air conditioners for each type of heat recovery in each city.

Table 3. Energy tariff

	Company	Cost per Demand [R$/KW]	Cost per energy [R$/KWh]	
			Peak	Off peak
Recife	CELPE	11.12	1.10854	0.19624
Rio de Janeiro	LIGHT	11.27	0.79258	0.17913
São Paulo	AES Eletropaulo	7.01	0.56387	0.18406
Brasília	CEB	6.0670007	0.8867976	0.2590213

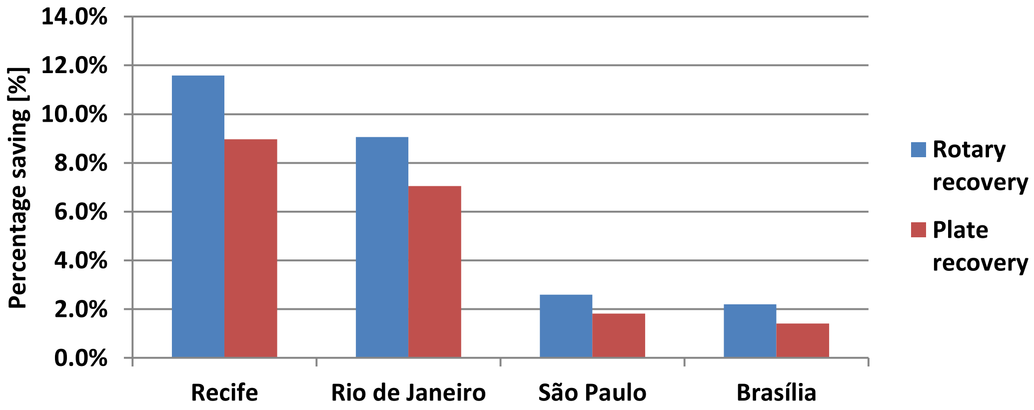

Figure 7. Percentual reduction of air conditioner system for each type of heat recovery and for each city.

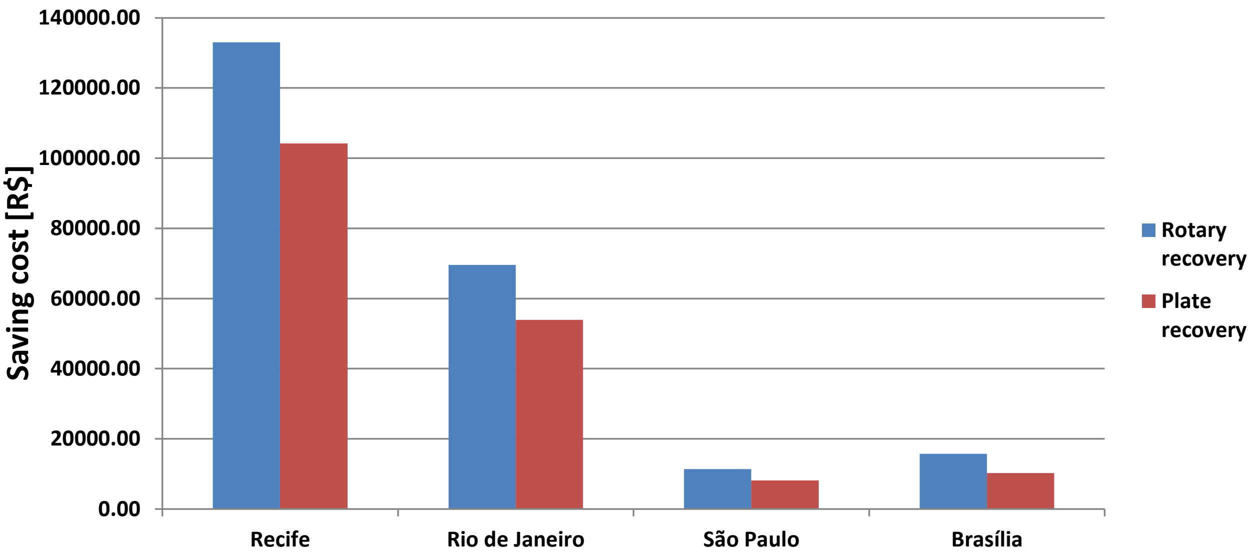

Figure 8. Savings in cost for each type of recovery and for each city.

6. CONCLUSIONS

The results demonstrate that the use of heat recovery provides a reduction in consumption and in cost for all the cities studied. Due to the high humidity in Brazilian cities, enthalpy heat recovery provided better results than sensible heat recovery.

The energy savings for heat recovery were between 7% and 12% for cities with hot weather and of about 2% for cities with warm weather; therefore, using heat recovery is more important for cities such as Recife and Rio de Janeiro, which have more uniform climatic conditions over the year.

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