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Operating Room Ventilation Systems Best Practices Guide for Energy Efficiency, Health and Safety

A GREENING HEALTH CARE RESEARCH PROJECT

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This Best Practices Guide (Guide) is for use by Facility Directors of acute care hospitals to help evaluate their existing operating room ventilation systems, and direct staff and service providers in making their operating performance and energy efficiency the best they can be. The Guide is provided as a technical resource for Greening Health Care member hospitals. Greening Health Care is a program of the Living City managed by Toronto and Region Conservation.

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1. Background

Operating Room (OR) ventilation is the most energy intensive service in acute care hospitals, which in turn are one of the most energy intensive commercial/institutional building types in North America. As well, proper ventilation is essential to the health and safety of hospital staff, surgical teams and patients. Different hospitals are designed and retrofitted with different system and control configurations, and system operating practices vary widely. For all these reasons, at the beginning of 2016, Greening Health Care initiated an applied research project aimed at documenting best practices for OR ventilation design, retrofit, operation and control, for use by member hospitals in optimizing the energy performance of their facilities.

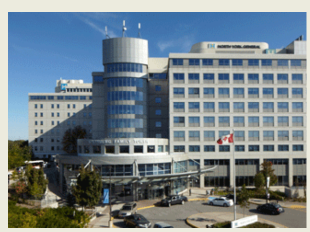
Four major acute care hospitals took part in the project (see sidebar), providing technical input and review as well as information on their existing systems and operations. Utility company and industry sponsors also contributed technical knowledge as well as funding for the project. Findings were presented to and reviewed at the Greening Health Care workshop on November 30th 2016, and the webinar on December 14th 2016. (See Section 5 Pilot Hospital Findings). This Best Practices Guide presents the findings, conclusions and recommendations of the project.

About Greening Health Care

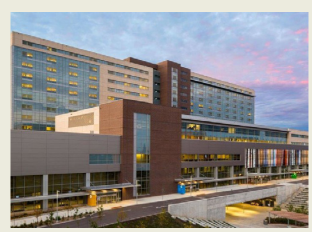
Founded in 2003, Greening Health Care is the largest program of its kind in North America, helping hospitals work together to lower their energy costs, raise their environmental performance and contribute to the health and well-being of their communities. Members manage data, assess their performance and track savings using a powerful online system. They share knowledge and best practices through workshops, webinars and networking to help plan, implement and verify improvements. This is a program of The Living City managed by Toronto and Region Conservation.

Kingston General Hospital
- Kingston, Ontario
- 1,238,560 ft2
- 440 beds
- Serves 500,000 people
- Acute care teaching hospital

SickKids Hospital
- Downtown Toronto
- 2,840,913 ft2 across three sites
- 283.9 average number of beds occupied daily
- 301,997 annual ambulatory visits
- Children's hospital and research facility



North York General Hospital
- North Toronto
- 677,691 ft2 (main hospital)
- 419 acute beds, 192 long-term beds
- 137,123 outpatient volume
- Acute care, ambulatory and long-term care services



Humber River Hospital
- North Toronto
- 1,826,205 ft2
- 656 beds
- Serves a catchment area of more than 850,000 people
- Acute care hospital

2. Introduction

Depending on local weather conditions and utility prices, a typical 25,000 cubic feet per minute (cfm) OR ventilation system can cost as much as $125,000/year or more in electricity and thermal energy consumption. Proper design/retrofit, operation and control can reduce this cost by as much as 65%, while ensuring healthy and safe environmental conditions for surgical teams and patients.

For new hospital design, this Best Practices Guide documents the energy use and utility cost implications of alternate system configurations, and lays out the operating, control, measurement and verification requirements for optimizing in-service energy use. For existing hospitals, it is generally not economic to modify the system configuration (for example, installing heat recovery or recirculation), so the Guide is intended to provide the optimal operation, control, measurement and verification practices to get the best performance out of whatever system is installed.

3. Best Practices

The individual measures for consideration with every OR ventilation system, to be implemented where practicable, are laid out below and provided as a checklist in Appendix A. See Section 4 for required air change rates and space conditions, and Section 8 for the relative utility costs of the different design configurations and operations.

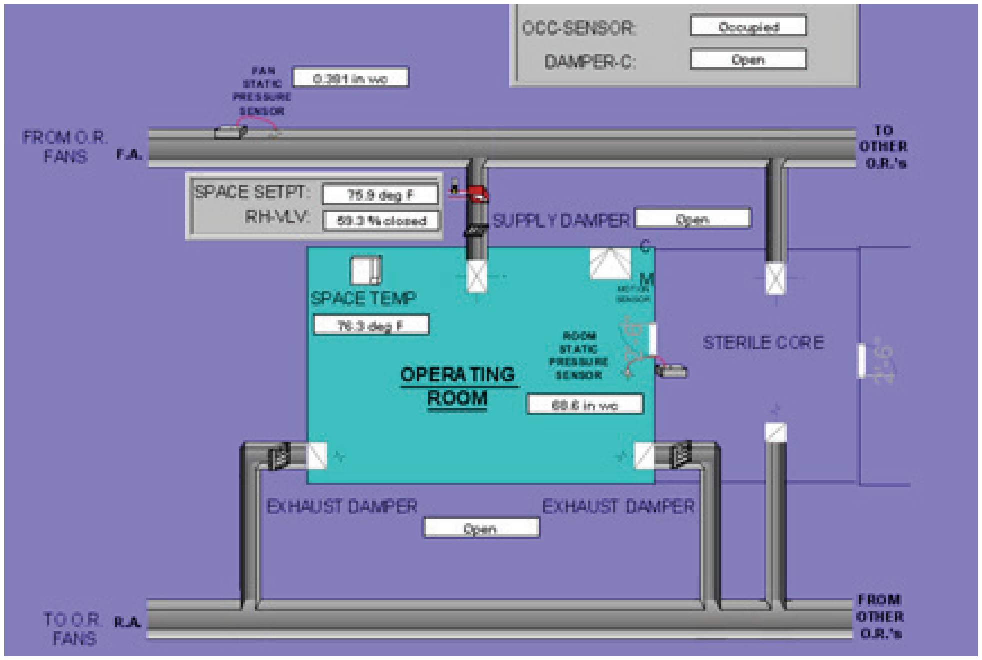
3.1 Unoccupied Setback

The universal strategy for all system configurations is to reduce the airflow to each OR and the other areas served by the system when not in use, along with adjustments to supply air and space temperature set-points. Figure 1 illustrates the requirements for implementing setback as follows:

- Volume control devices on the air supply and exhaust to each OR and other rooms/areas
- Relative pressure monitoring of the ORs against adjacent areas
- Occupancy sensor(s) in each room
- Volume control Variable Frequency Drives (VFDs) on supply and exhaust fans
- Space temperature reset so that reheat coils are disabled unless high or low limits are reached

Airflow setback during unoccupied periods reduces energy use for preheat, cooling and humidification in proportion to the airflow reduction. Fan power savings are even greater because of the affinity (cube) law, and reheat savings are proportionately greater because of reduced heat loads in the unoccupied rooms. Section 8 of this Guide shows the savings due to setback for the different system design configurations.

Figure 1.
Setback implementation requirements



3.2 Air Change Rates

Test the overall air volume and the supply to each OR, and rebalance to the required amounts as laid out in this Guide.

3.3 Recirculation

- Operationalize air recirculation for systems which have that capability or can be readily retrofitted.
- Ensure proper capture and monitoring of anesthetic gases, and that the required minimum outside air is maintained at all times when any OR is in use.

3.4 Airflow Control

- Install reliable and repeatable volume control devices on the air supply to and exhaust from each individual OR. Test and calibrate for required occupied and unoccupied air volumes at least annually.
- Install reliable and repeatable volume control devices on the air supply to and exhaust from each other space where airflow is to be set back during unoccupied periods. Test and calibrate for required occupied and unoccupied air volumes at least annually.
- Install airflow monitoring stations on total and outside air supply and total exhaust volumes for the air handling system. Test and calibrate at least every two years.

3.5 Monitoring and Control

- Install temperature and humidity sensors with continuous local and central monitoring for every individual operating room as well as the combined exhaust air.
- Install occupancy and relative pressure sensors with continuous monitoring for every individual OR, and for other spaces where airflow is set back during unoccupied periods.
- Verify proper operation and calibration of sensors monthly.

3.6 Control Set-points

- Maintain OR space temperature (other than Burn Unit) between 65°F (18°C) and 73.5°F (23°C) to suit surgical team requirement.
- For Burn Unit OR the range is 75°F (24°C) to 86°F (30°C).
- Maintain OR relative humidity (RH) between 30% and 60% at all times. Provide central alarm if RH exceeds 58% and local alarm if RH exceeds 60%.
- Automatically reset system supply air temperature down to stay within upper RH limit. During humid outdoor conditions the supply air temperature will go down to 50°F (10°C); during normal operating conditions the supply air temperature can rise to 60°F (16°C).
- Automatically reset chilled water supply temperature as required to maintain supply air temperature.

3.7 Measurement and Verification

Rigorous commissioning and ongoing monitoring are essential to verify that the system is operating as intended and continues to do so over time. Recommended verification procedures are as follows:

- Test and verify every 12 months occupied and unoccupied supply airflows for every individual controlled zone and the system as a whole.
- Download and analyze trend logs to verify accurate and consistent control:
  - OR space temperatures and RH;
  - OR differential pressures;
  - supply and exhaust air temperatures;
  - outside air volumes;
  - chilled water supply temperature.

4. Code and Regulatory Requirements

In Canada, Canadian Standards Association (CSA) Z 317 governs the requirements for operating room ventilation systems and space conditions. The equivalent regulation for the United States is ASHRAE 170. For supply air, the recommendation of both CSA and ASHRAE is 20 air changes per hour (ACH). For outside air, ASHRAE 170-2008 requires 4 ACH (20% outside air) while CSA Z 317-15 is more restrictive and requires 6 ACH (30% outside air).

CSA Z 317-15 (5.2.1)

All rooms and areas within an Health Care Facility (HCF) shall be ventilated to ensure an air exchange adequate to control contaminant levels, temperature, and humidity while minimizing stratification and drafts. Note: Table 1 provides minimum values for temperature, humidity, and air exchanges based on the function of each room or area.

ASHRAE HVAC Design Manual for Hospitals and Clinics – second edition

Minimum air exchange rates for the various types of spaces should comply with ANSI/ASHRAE/ASHE Standard 170-2008 (see Table 3-3). This standard list minimum air exchange rates for both ventilation air (outdoor air) and total supply air. Some state and local codes may have minimum air exchange rates that differ from the ASHRAE standard. In such instances, the designer should design for the higher value.

Table 1.
HVAC design criteria for ORs: OCCUPIED MODE

Reference	Function	Type	Minimum outdoor air changes per hour	Minimum total air changes per hour	Relative pressurization	Temperature °C	Temperature °F	Relative humidity %
CSA Z 317-15 (Table 1)	Operating rooms	I	6	20	Positive	18-23	64-73	30-60
ASHRAE 170-2008 (Table 3-3)	Operating rooms	B&C	4	20	Positive	20-24	68-75	30-60

Table 2 shows the setback (minimum) airflows to be met in unoccupied mode.

CSA Z 317-15 (6.5.4.1.1)

Air-handling systems for Type I areas may be operated at a reduced level when the space is unoccupied. The air circulation system should maintain at least six air changes per hour unless the space is continuously monitored for temperature, humidity, and (where applicable) relative pressurization and airflow. Where circulation systems maintain less than six air changes per hour, these parameters shall be kept within the design ranges specified in Table 1.

ASHRAE 170-2008 (7.1.C)

For spaces that require a positive or negative pressure relationship, the number of air changes can be reduced when the space is unoccupied, provided that the required pressure relationship to adjoining spaces is maintained while the space is unoccupied and that the minimum number of air changes indicated is re-established anytime the space becomes occupied. Air change rates in excess of the minimum values are expected in some cases in order to maintain room temperature and humidity conditions based upon the space cooling or heating load.

Table 2.
HVAC design criteria for ORs: UNOCCUPIED MODE

Reference	Function	Type	Minimum outdoor air changes per hour	Minimum total air changes per hour	Relative pressurization	Temperature °C	Temperature °F	Relative humidity %
CSA Z 317-15 (Table 1)	Operating rooms	I	Not Mentioned	6	Positive	18-23	64-73	30-60
ASHRAE 170-2008 (Table 3-3)	Operating rooms	B&C	Not Mentioned	As low as possible	Positive	20-24	68-75	30-60

Figure 2 shows the acceptable band within which the space conditions for every individual OR must be maintained. In particular, the upper limit of 60% RH must not be exceeded so that the safety of materials and products within the OR is not compromised.

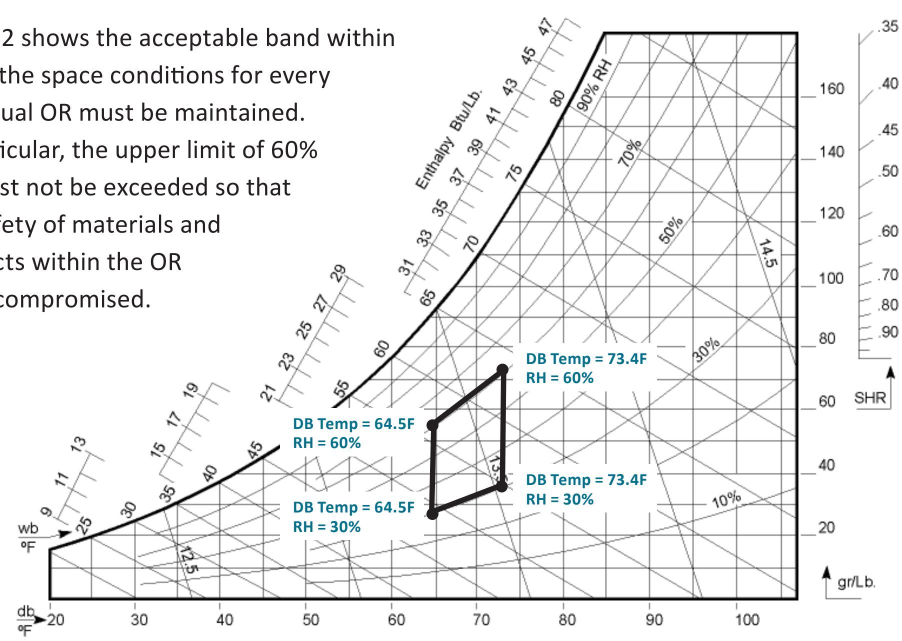


Figure 2.
OR space conditions: acceptable band

5. Pilot Hospital Findings

The four hospitals which took part in this project have a combined total of ten OR ventilation systems, of which five are designed with recirculation capability, but none is being used in either occupied or unoccupied mode. The hospital representatives provided detailed information on their systems, along with insights and recommendations on where and how improvements could be made which are incorporated into the Guide. Tables 3-8 summarize the systems and operations for the four hospitals.

Table 3.
Pilot hospital system configurations

Hospital #	Thermal Wheel — Unoccupied Setback	Heat Recovery Chiller — Unoccupied Setback	No Heat Recovery — Unoccupied Setback	No Heat Recovery	Heat Recovery Chiller
1	✓				
2		✓			✓
3			✓	✓	
4	✓				

The proportion of total air handling unit volume supplying the ORs for the four pilot hospitals ranged between 35% and 55%, with the remainder going to corridors, recovery and service areas. The maximum, minimum and average air changes per hour for the four pilot hospitals are presented in Table 4.

Table 4.
Pilot hospital total air changes per hour, as reported by hospitals

Hospital #	# of Operating Rooms	Occupied			
		Maximum	Minimum	Average	Note
1	12	27	20	24	11 ORs are higher than the standard
2	16	27	20	22	9 ORs are higher than the standard
3	15	24	14	21	1 OR is below the standard and 8 ORs are higher
4	20	20	20	20	
CSA Requirement		N/A	20	N/A	

Hospital #	# of Operating Rooms	Unoccupied			
		Maximum	Minimum	Average	Note
1	12	12	9	11	All ORs are higher than the standard
2	16	23	9	15	All ORs are higher than the standard
3	15	21	10	18	All ORs are higher than the standard
4	20	20	20	20	
CSA Requirement		N/A	6	N/A	

Table 5.
Presence of sensors in pilot hospitals

Hospital #	Unoccupied				
	Temperature	Humidity	Pressurization	Occupancy	Note
1	✓	✖	✓	✓	
2	✓	✖	✓	✓	Only 2 ORs are equipped with humidity sensors
3	✓	✓	✓	✓	
4	✓	✓	✓	✓	
CSA Requirement	✓	✓	✓	✓*	
Best Practice	✓	✓	✓	✓	

* Only for systems that have the capability to go to unoccupied mode CSA-Z317.2-15-6.5.4.1.3

Table 6.
Pilot hospital ventilation controls

Hospital #	Variable Air Volume Box			Air Flow Station
	Individual Supply	Individual Exhaust	Common Exhaust	
1	✓	✖	✓	✖
2	✓	✓	✖	✓
3	✓	✓	✖	✓
4	✓	✓	✖	✖
Best Practice	✓	✓		✓

Table 7.
Pilot hospital central system set-points and controls

Hospital #	Trend-logs Set-up	AHU Supply Air Temperature (°F)	Chilled Water Supply Temperature (°F)	Chilled Water Supply Temperature Reset by BAS	Back-up AHU	Running Main & Backup AHU
1	✓	55-60	41	?	✖	✖
2	✓	53-57	42.5	?	✓	✓
3	✓	46-50	42.5	✓	✖	✖
4	✓	57-61	45	✖	✓	✓
Best Practice	✓	50-58	41-50	✓		✓

Table 8.
Pilot hospital operating room set-points and controls

Hospital #	OR Temperature Reset by BAS	OR Minimum Temperature (°F)	OR Maximum Temperature (°F)	OR Minimum Relative Humidity (%)	OR Maximum Relative Humidity (%)	Does The Hospital Have a Burn Unit?	Burn Unit Temperature (°F)	Burn Unit Relative Humidity (%)
1	✓	64	69	No Sensor	No Sensor	✖		
2	?	66	74.8	57.7	71	✓	85	No Sensor
3	✓	64	72	45	65	✖	✖	✖
4	?	67	73	42	54	✖	✖	✖
CSA* Recommendation		64.5	73.4	30	60		75-86	30-60
Best Practice	✓	64.5	73.4	30	60		75-86	30-60

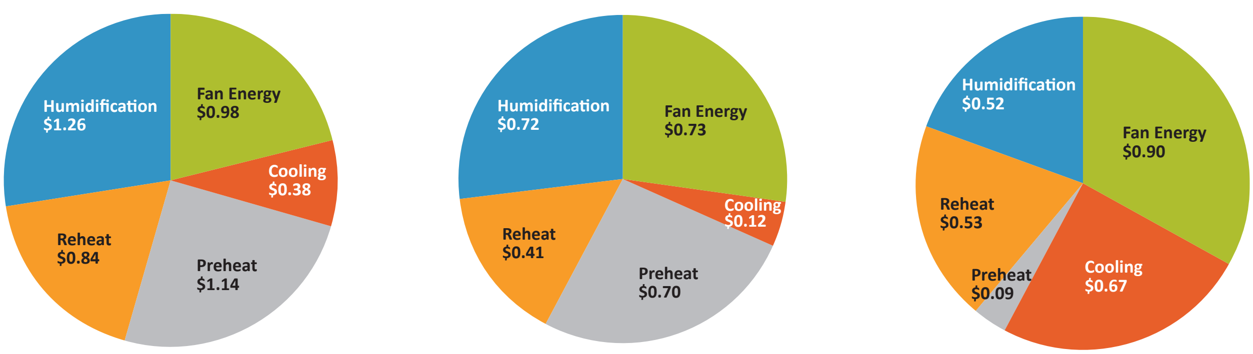
6. Energy Use Breakdown: Reference Ventilation System

The energy use breakdown of a reference OR ventilation system is shown in Figure 3 for weather conditions in Toronto ON, Calgary AB and Sacramento CA. The parameters of this reference system are provided in Table 9.

Table 9.
Reference OR ventilation system parameters

Supply Air (cfm)	Outside Air	Schedule of Operation	Heat Recovery	Unoccupied Setback
25,000	100%	24 / 7	No	No
Supply Fan Total Setpoint (in-wc)	**Exhaust Fan Total Setpoint (in-wc)**	**Supply Air Temperature (F)**	**Average Room Temperature (F)**	**Return Air Relative Humidity (%)**
4	1.5	55	72	50%

Figure 3.
Energy cost breakdowns of a reference OR ventilation system under Toronto, Calgary and Sacramento weather conditions ($/cfm)



TORONTO
Electricity rate: 0.12 C$/kWh
Gas rate: 0.25 C$/M3

CALGARY
Electricity rate: 0.09 C$/kWh
Gas rate: 0.12 C$/M3

SACRAMENTO
Electricity rate: 0.11 US$/kWh
Gas rate: 0.17 US$/M3

Energy Source	Components	Toronto Total	Calgary Total	Sacramento Total
Electricity (kWh)	Fan Energy	203,727	203,727	203,727
	Cooling	79,000	32,194	151,358
Natural Gas (M3)	Preheat	113,632	145,316	12,847
	Reheat	84,090	84,827	77,938
	Humidification	125,525	150,254	76,561

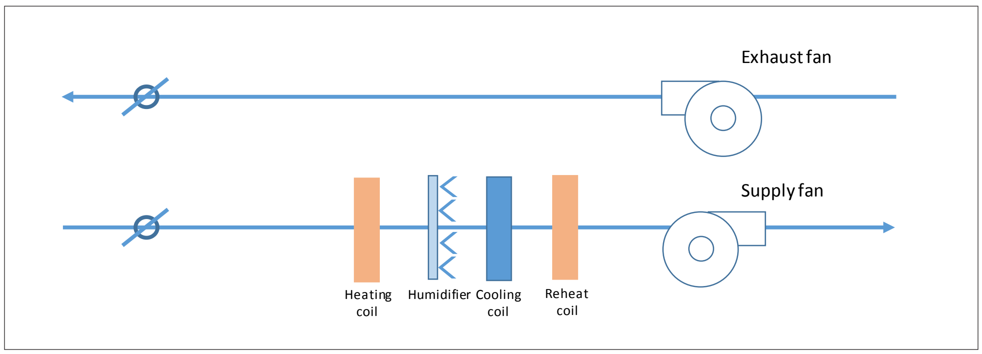
7. System Design Configurations

The basic, reference system (100% outside air with no heat recovery), and the four other system design configurations considered in this research, are described as follows:

7.1 Reference System (No Heat Recovery)

A constant volume system with 100% outside air supply and 100% exhaust is the reference system against which the rest are compared.

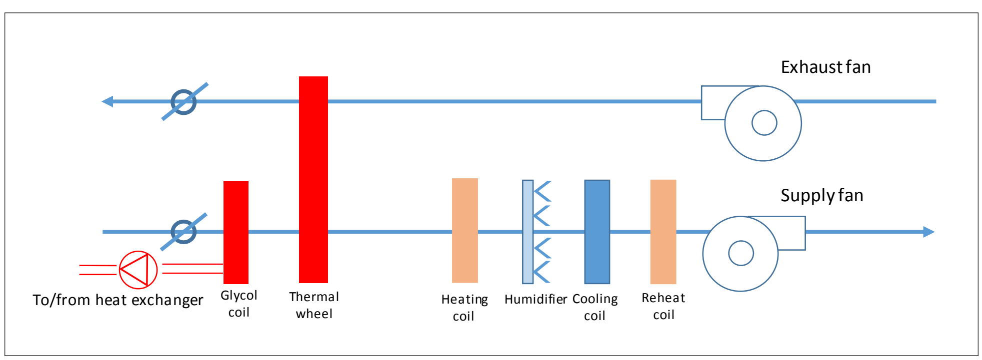
Figure 4.
No heat recovery system configuration



7.2 Thermal Wheel Heat Recovery System

The heat recovery wheel rotates between incoming outside air and exhaust air. It recovers both heat and humidity from exhaust to incoming air in winter, and also provides some pre-cooling of outside air on hot summer days. Additional fan power is used overcoming the static pressure loss through the wheel. A pre-heat coil is provided for the incoming air to prevent frost forming on the exhaust side of the heat recovery wheel in very cold weather.

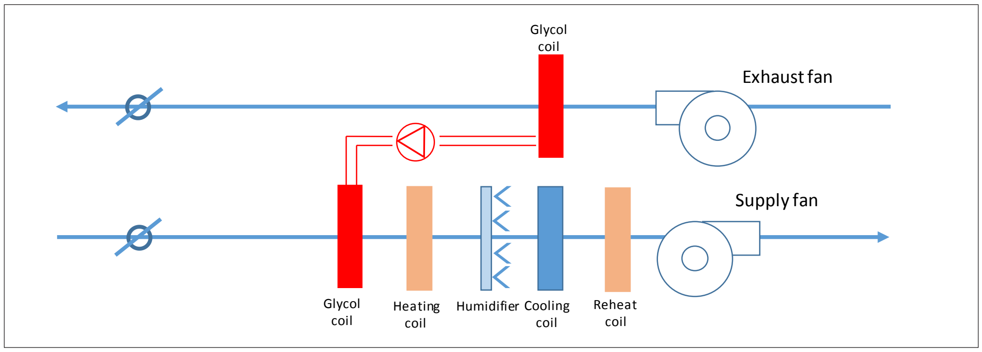
Figure 5.
Thermal wheel heat recovery system configuration



7.3 Glycol Coil Heat Recovery System

Multi-row coils transfer heat from exhaust air to incoming supply air by means of a pumped glycol loop. Additional fan power is used overcoming the static pressure loss through the coils.

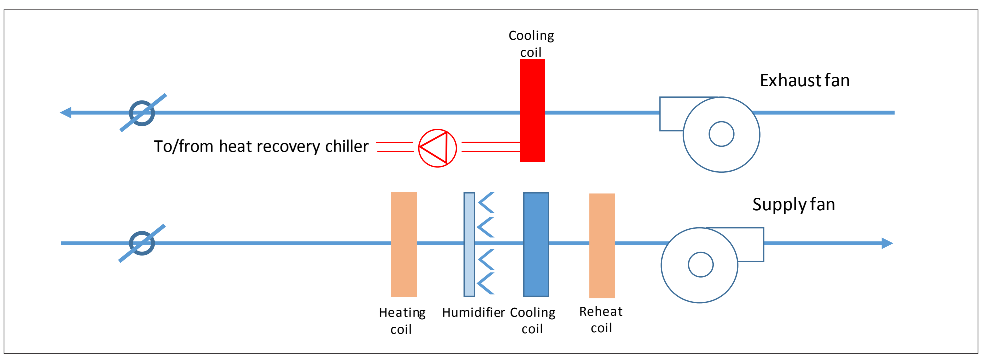
Figure 6.
Glycol coil heat recovery system configuration



7.4 Heat Recovery Chiller System

A heat recovery chiller typically supplies chilled water throughout the hospital in winter to cool areas such as data centres and refrigeration, and to recover heat from exhaust air leaving the building. The machine serves as a heat pump, generating hot water which can be used for a variety of purposes including ventilation reheat. Additional energy is used to run the heat recovery chiller and pumps, and by exhaust fans to overcome the static pressure loss through the heat recovery coils.

Figure 7.
Heat recovery chiller system configuration



7.5 Air Recirculation System

A proportion of exhaust air from the surgical suite is recirculated back into the supply stream, mixing with at least the minimum volume of incoming outside air before delivery to the ORs, and thereby recovering heat and humidity in winter and reducing latent cooling loads in summer.

Figure 8.
Air recirculation system configuration

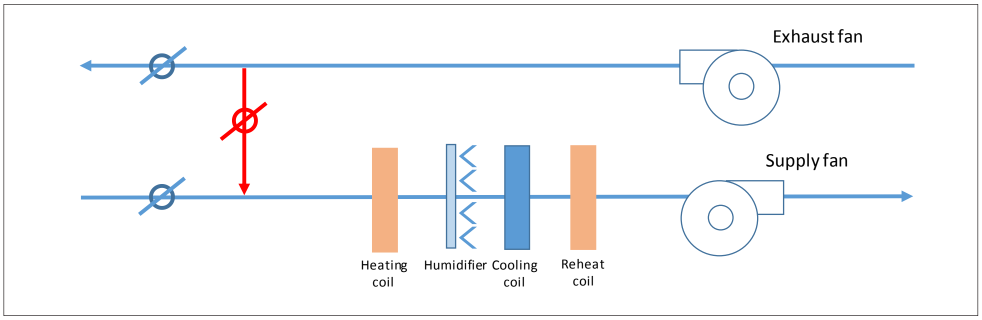


Table 10 summarizes the relative energy benefits and offsets of each design configuration.

Table 10.
Energy considerations of system design configurations

Design Configuration	Energy Considerations
No heat recovery system	Reference system
Thermal wheel heat recovery system	Recovers as much as 80% of sensible heat and humidity from exhaust air in winter, along with a smaller pre-cooling and dehumidifying effect in summer. Additional fan power due to static pressure loss through the wheel (Note 1).
Glycol coil heat recovery system	Recovers around 45% of sensible heat from exhaust air in winter. Additional pump energy and fan power due to static pressure loss through the intake and exhaust coils (Note 1).
Heat recovery chiller system	Recovers sensible heat throughout the hospital for use in reheat coils, and to supplement other heating. Additional energy to run the machine, and fan power due to exhaust air heat recovery coils (Note 1).
Air recirculation system	Reuses conditioned return air, recovering heat and humidity in winter, and cooled and dehumidified air in summer.

Note 1: bypass dampers can be installed to avoid static pressure losses by diverting air around heat wheels and coils when heat recovery is not required.

8. Energy Cost Comparison for Different System Design Configurations

Figures 9, 10 and 11 present the relative energy costs per cfm (using gas-fired boiler heating and humidification and electric cooling, at 2015 rates) for each of the system design configurations, and for typical weather conditions in Toronto, Calgary and Sacramento, respectively. Tables below the bar charts show the relative energy and utility cost savings compared with the 25,000 cfm reference system (no heat recovery).

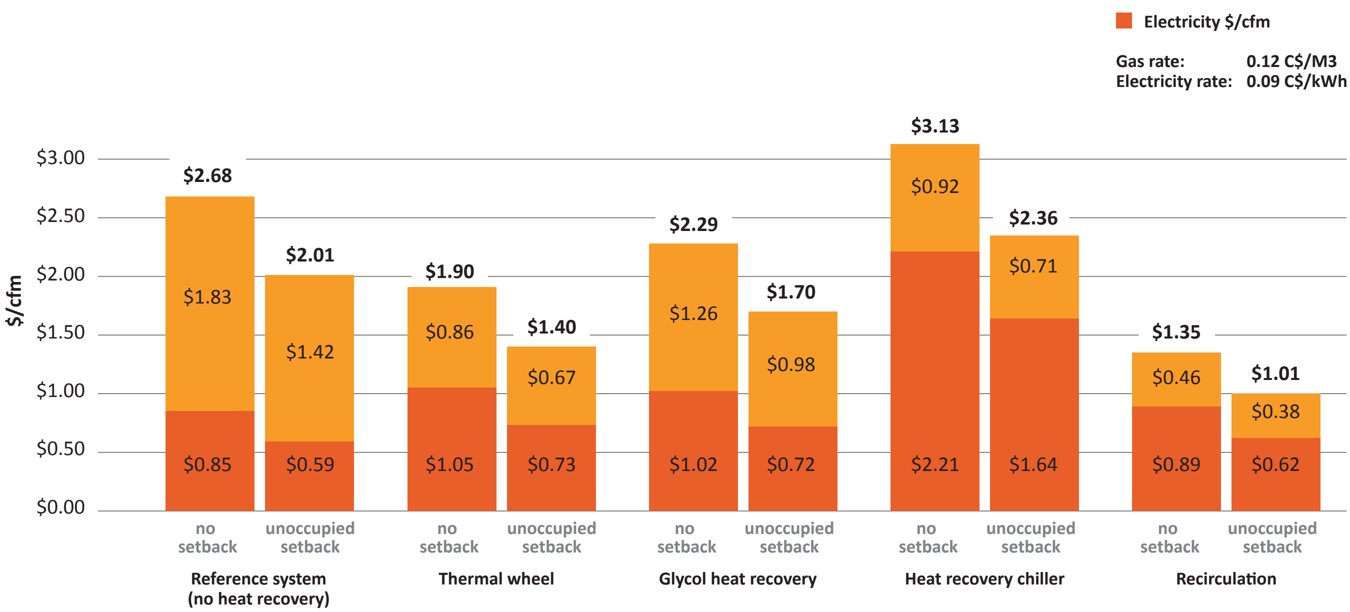
Figure 9.
OR AHU energy cost breakdown for different design configurations –
Toronto weather conditions

Savings relative to reference system	Reference system (no heat recovery)		Thermal wheel		Glycol heat recovery		Heat recovery chiller		Recirculation	
	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback
Total $	$0	$27,962	$35,417	$55,849	$18,839	$55,051	$4,112	$31,253	$66,149	$79,634
Gas M3/yr	0	72,731	166,987	202,146	98,136	148,786	169,530	204,116	236,659	251,751
Elec kWh/yr	0	81,491	-52,751	44,274	-47,457	148,786	-318,923	-164,804	58,200	139,132

Figure 10.

OR AHU energy cost breakdown for different design configurations –

Calgary weather conditions

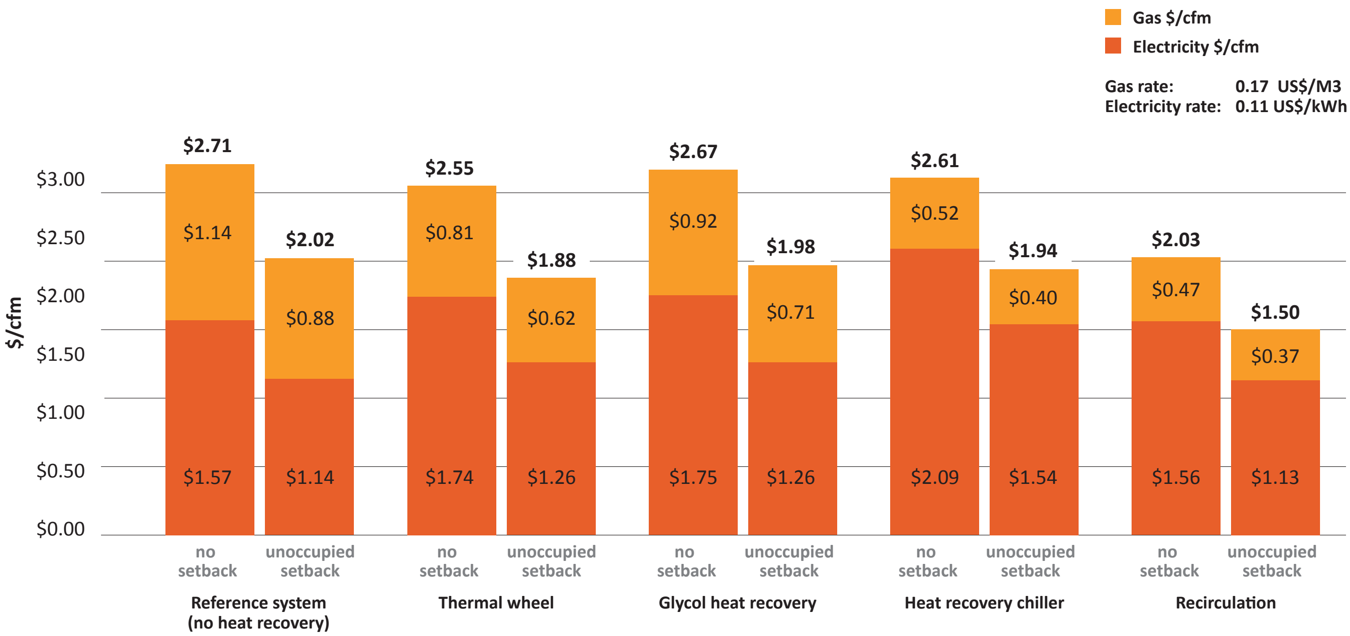


Savings relative to reference system	Reference system (no heat recovery)		Thermal wheel		Glycol heat recovery		Heat recovery chiller		Recirculation	
	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback
Total $	$0	$16,657	$19,282	$31,930	$9,741	$37,096	-$11,299	$7,979	$37,987	$46,646
Gas M3/yr	0	85,589	201,538	241,781	117,493	176,646	188,483	231,664	284,200	300,478
Elec kWh/yr	0	70,959	-54,475	32,407	-48,427	176,646	-376,857	-220,234	43,145	117,654

Figure 11.

OR AHU energy cost breakdown for different design configurations –

Sacramento weather conditions



Savings relative to reference system	Reference system (no heat recovery)		Thermal wheel		Glycol heat recovery		Heat recovery chiller		Recirculation	
	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback	no setback	unoccupied setback
Total $	$0	$17,200	$3,979	$20,689	$1,004	$17,463	$2,446	$19,192	$21,234	$34,420
Gas M3/yr	0	37,653	48,852	75,513	31,782	62,284	90,645	107,903	98,684	112,423
Elec kWh/yr	0	97,771	-39,091	71,141	-39,773	62,284	-117,215	7,800	40,455	138,665

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Appendix A: Checklist

OR Ventilation Assessment Action Checklist

Hospital: ______________________

Contact Email: ______________________

ACTION		Already Implemented	Planned	Consider	Reject / NA	DETAILS
#	NAME					
	OPERATIONAL CHANGES					
1	Test and adjust supply and exhaust airflows for individual spaces to match CSA requirements for both occupied and unoccupied periods					
2	Reset supply air temperature to maintain RH in all ORs while minimizing reheat					
3	Reset discharge air static pressure to optimize fan power					
4	Reset space conditions during unoccupied periods to minimize simultaneous cooling and heating					
5	Reset chilled water supply temperature to achieve required supply air temperatures					
6	(If standby AHUs installed) operate both AHUs in parallel					

ACTION		Already Implemented	Planned	Consider	Reject / NA	DETAILS
#	NAME					
	RETROFIT MEASURES					
1	Install VFDs to enable efficient occupied/unoccupied air volume reset					
2	Install or replace volume control boxes on individual air supply and exhaust to each space					
3	Install differential pressure monitoring in ORs and other areas					
4	Install temperature and RH sensors for individual ORs					
5	Install airflow monitoring stations on supply and exhaust fans					
6	Implement air recirculation for 100% outside air systems					
7	Install low static pressure loss heat recovery on 100% outside air systems					
8	Consider anesthetic gas monitoring and system reset controls					
9	Consider anesthetic gas scavenging and recycling					

Revised November 30, 2016