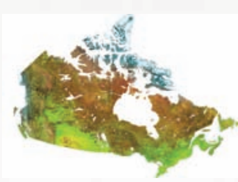
2ND EDITION

BUILDING OPERATION OPTIMIZATION

Advanced Recommissioning (RCx) Course

Adapted by Natural Resources Canada's CanmetENERGY



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Building Operation Optimization

ADVANCED RECOMMISSIONING (RCX) COURSE

2nd Edition

DEVELOPED BY PORTLAND ENERGY CONSERVATION, INC. (PECI)
ADAPTED BY NATURAL RESOURCES CANADA'S CanmetENERGY

January 2010

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ADVANCED RECOMMISSIONING (RCX) COURSE[1]

This *Advanced Recommissioning (RCx) Course* owned by Natural Resources Canada (the "RCx Course") has been originally developed by Portland Energy Conservation, Inc. (PECI). The Canadian adaptation[2,3] of the RCx Course has been managed by Natural Resources Canada's CanmetENERGY in collaboration with the Office of Energy Efficiency (OEE) and under the ecoENERGY for Buildings Program of Natural Resources Canada (NRCan).

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Terri Meyer Boake, University of Waterloo (building picture).

Ce document est disponible en français sous le titre :
« Cours avancé de recommissioning (RCx) ».

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1 See the RCx Glossary for definitions of the terminology used by Natural Resources Canada: www.canmetenergy.nrcan.gc.ca/glossary_RCx.html

2 Imperial units have been converted to metric units where useful. Sometimes to reflect the market reality or because the unit conversion was not necessary to understand the concept presented, original imperial units were kept as is.

3 U.S.A. monetary units (USD, $) have been converted at-the-money (ATM) to Canadian monetary units (CDN, $) as per conversion rates published by the Bank of Canada for January 31st 2008. No other conversion rate factors have been applied to take also account of other differences in the costs that might happen between U.S.A. and Canada.

ABOUT THIS ADVANCED RECOMMISSIONING (RCX) COURSE

This course covers the recommissioning (RCx) process: planning, investigation, implementation and hand-off (see the *RCx Standardised Process Flowchart*), and emulates the actual phases of recommissioning to provide participants with a cohesive understanding of the process from start to finish. A discussion on commissioning and recommissioning highlights the differences between these processes (design-construction-testing vs. investigation-implementation), as well as the similarities between the two (system testing, trending, etc). The course also covers persistence strategies for facility operating staff and 3rd-party recommissioning providers to maintain the benefits of the process over the life of a building.

Training topics include: the system approach, efficient methods for uncovering problems, working with the building staff, calculating savings, implementing findings, providing targeted documentation and training, and on-going commissioning best practices.

Students are invited to participate in group activities based on real-world project data from actual recommissioning projects to reinforce the principles demonstrated during the class.

Planning Phase

This module focuses on the tasks that typically occur during the planning phase of a recommissioning project. These include, but are not limited to: building pre-screening, benchmarking and utility bill analysis, project scoping, including trending and data logging issues.

Investigation and Implementation Phases

During the investigation phase, the commissioning provider performs a detailed analysis of operational improvements and energy conservation opportunities. This module provides participants with a mixture of classroom lecture and group activities to demonstrate how to identify these opportunities. Using engineering fundamentals, methodologies, and tools, students learn how to assess potential energy savings and report results in a consistent manner. An overview of recommissioning findings and in-depth evaluation of several of the most common measures expose participants to typical investigation results and examples of energy and cost savings potential. Potential systems for evaluation include:

- Pumping
- Ventilation
- Economizers
- Reset strategies and interactions
- Terminal units
- Lighting controls
- Schedule issues
- Cooling tower reset
- Proper setpoints

Results from in-class exercises are used to illustrate various implementation methodologies and techniques for selling recommissioning services.

Hand-off Phase

This module focuses on the tasks and deliverables that are typically part of the hand-off phase of the recommissioning process. The discussion reemphasizes how “persistence” and “recommissioning” fit into the big picture of ongoing building performance. Students learn how to develop a successful on-going commissioning plan to ensure the improvements implemented during the recommissioning process persist over time. The on-going tasks include, but are not limited to: facility staff training, re-benchmarking and utility bill analysis, best practices for maintaining optimized system operation, including trending and data analysis techniques used for troubleshooting and performance verification.

The final discussion touches upon the International Performance Measurement and Verification Protocol (IPMVP) and how it may impact a recommissioning project.

ACKNOWLEDGEMENTS

A great number of people have provided information and/or guidance during the development and adaptation of this document. The Natural Resources Canada's CanmetENERGY would like to thank the following individuals for their assistance, in addition to those involved in the development of the original document by Portland Energy Conservation, Inc. (PECI):

NRCan's Advanced Recommissioning (RCx) Course: Alexandre Monarque, Sonia Ringuette, Gilles Jean, Julie Bossé, Alain Trépanier, Marius Lavoie, Patrick Reghem, Karen Duchesneau, Sylvie Lavoie, John House, Maria Corsi, Daniel Choinière, Sophie Hosatte from NRCan's CanmetENERGY; Philip B. Jago, Pierre Guèvremont, Ian Meredith, Grant Miles, Debby Corbin from NRCan's Office of Energy Efficiency (OEE); Guy Turgeon and Annie Pageau from Therméca; Jean Bundock from Roche Consulting Group.

As part of the various consultations conducted, numerous other organisations provided comments and suggestions for improvements. Their efforts are also gratefully acknowledged.

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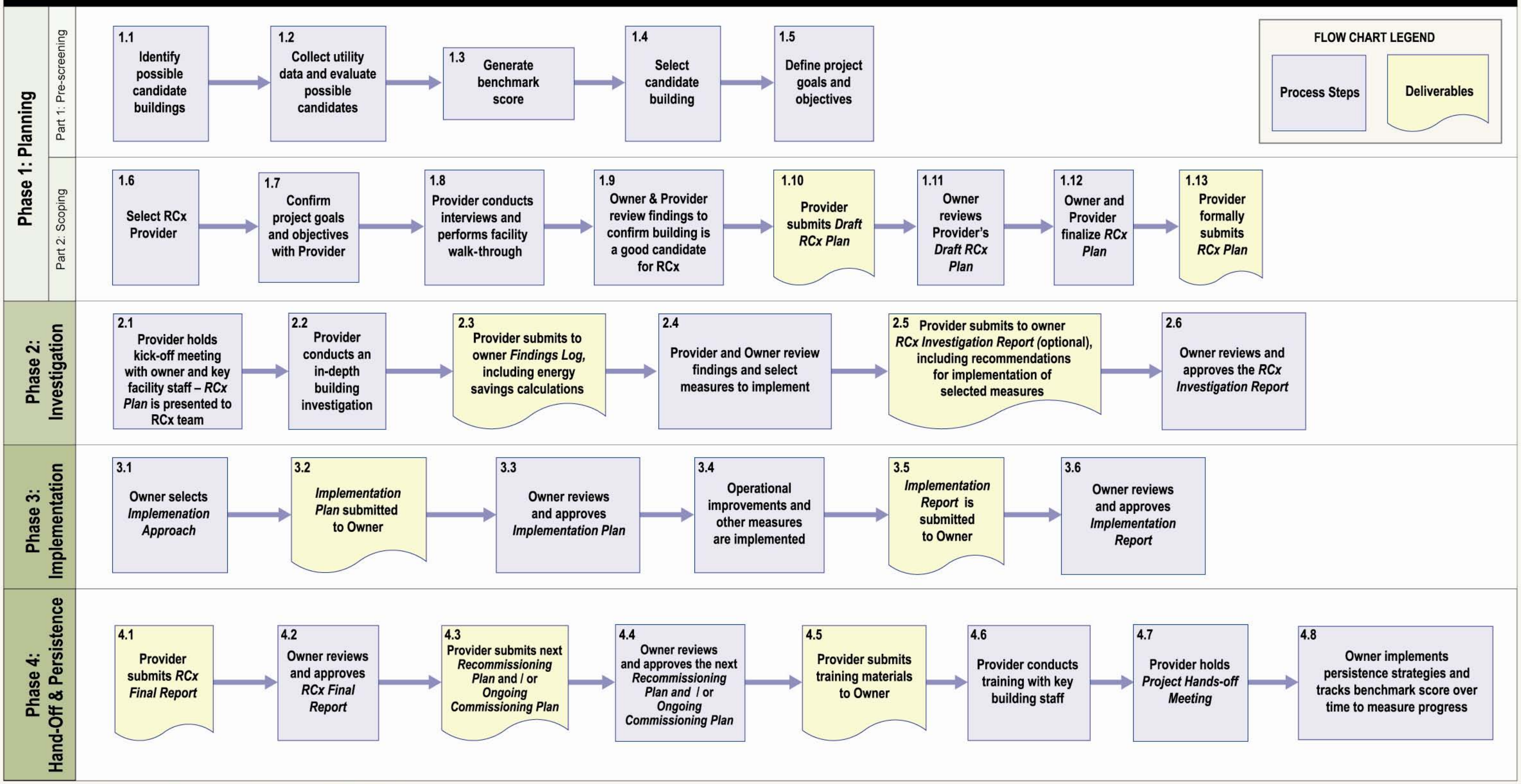
LIST OF ACRONYMS

AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	Building Automation System
CaGBC	Canada Green Building Council
Cx	Commissioning
DDC	Direct Device Control
DP	Differential Pressure
EMCS	Energy Management Control System
EPA	Environmental Protection Agency
EPC	Energy Performance Contract
ESCO	Energy Service Company
FDD	Fault Detection and Diagnostics
HDD	Heating Degree-Days
HVAC	Heating, Ventilation, and Air Conditioning
IEQ	Indoor Environmental Quality
kW	Kilowatt
kWh	Kilowatt hour
LEED	Leadership in Energy and Environmental Design
LEED AP	LEED Accredited Professional
LEED-EB™	LEED for Existing Building
LEED-NC™	LEED for new construction
m	Metre
NEI	Non-Energy Impact
NEB	Non-Energy Benefit
NLL	Night Low Limit
NRCan	Natural Resources Canada
OEE	Office of Energy Efficiency
O&M	Operation & Maintenance
PECI	Portland Energy Conservation, Inc.
RCx	Recommissioning
RFP	Request for Proposal
RFQ	Request for Qualifications
ROI	Return On Investment
TAB	Test And Balance
USGBC	U.S. Green Building Council
VFD	Variable Frequency Drive
W	Watt

Recommissioning (RCx) Process



www.canmetenergy.nrcan.gc.ca/eng/rcx.html

Building Operation Optimization
Advanced Recommissioning (RCx) Course

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Advanced Recommissioning (RCx) Course

Advanced RCx Course

- Provides a cohesive understanding of the RCx process from start to finish.
- Participants will learn technical methods for identifying RCx opportunities, and how to utilize resources and tools that help streamline and bring consistency to the RCx process.
- Industry professionals will gain hands-on experience in RCx operational improvement approaches, and improve their ability to deliver a quality RCx project.
- Targeted industry professionals are mostly engineers with experience in HVAC systems and building operations.

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Advanced RCx Course Overview

Advanced RCx Course

Introduction to Recommissioning (RCx)

Phase 1: Planning - Pre-screening and Scoping

Phase 2: Investigation

- Engineering fundamentals
- In-depth building investigation
- List of findings (common RCx measures)
- RCx investigation report

Phase 3: Implementation

- Plan and report with evaluation of savings potential

Phase 4: Hand-Off and Persistence

- RCx final report
- Plan for periodic RCx and ongoing Cx plan
- Persistence strategies and performance tracking

Conclusion

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Advanced RCx Course Overview (con't)

Advanced RCx Course

Activities

- Develop an RCx Plan
- Review system diagram and pump test analysis
- Perform a comprehensive pumping system analysis
- Evaluate savings associated with a pumping system
- Develop recommendation and estimate of savings for common RCx measures: schedule, setpoints, resets, economizers, ventilation control
- Develop enhanced sequence of operations and persistence matrix

Samples

- Recommissioning (RCx) Plan
- Issue Log Summary
- Implementation Summary Table
- Operational Persistence Matrix
- Overall Building Operation Plan
- Implementation Summary Matrix - Final
- Ongoing RCx Plan

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Advanced RCx Course Training Material

RCx Course Binder

- Presentation slides
- Activities forms, information and schemas
- Samples
- Unit conversion tables
- Hand-outs

Online Resources

www.canmetenergy.nrcan.gc.ca

- RCx Guide for Building Owners and Managers
- References, News, Events, etc.

IMPORTANT NOTICES

- Imperial units are converted to metric units where useful
  - U.S.A. monetary units are converted at-the-money (ATM) to Canadian monetary units (Bank of Canada's rates, 2008-01-31)

Advanced RCx Course

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Advanced Recommissioning (RCx) Course

Introduction to RCx

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Introduction to Recommissioning

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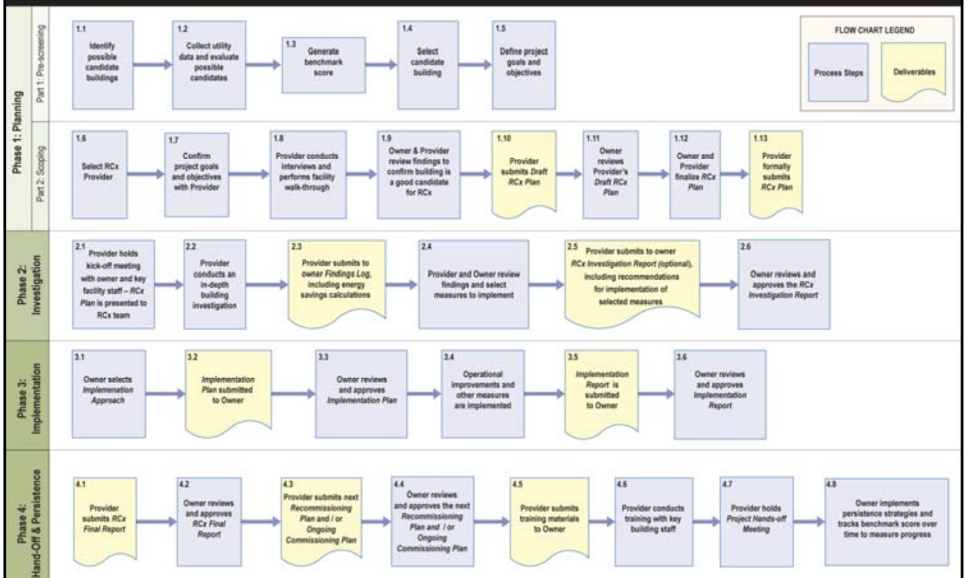
- Process
- Terminology
- Needs
- Benefits
- Costs

Recommissioning (RCx) Process



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What is Recommissioning (RCx)?

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Taking what you have…. and making it better!

- An activity in the life cycle of a building that applies a systematic process to improve an existing building's performance
- It provides a thorough, systems approach-based evaluation to identify problems and integration issues
- The main objective is to determine which "low cost/no cost" operational improvements may be made to the building currently in use, to improve occupant comfort and achieve energy savings
- This activity may be conducted alone, or as part of a renovation/modernization project

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Terminology

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Commissioning (Cx)

– A quality assurance process that begins at the design stage and continues through the first year of operation
– Ensures building is operated (optimally) as planned

Recommissioning (RCx)

– Re-optimization process (inspection, diagnosis and repair) for existing buildings
– Ensures building equipment and systems are operating optimally to meet current occupant needs

IMPORTANT NOTICE
The term "recommissioning" (RCx) has been chosen as a generic term for the commissioning of existing buildings. Retrocommissioning, while similar, is defined as a one-time service to existing buildings that have not previously been commissioned.

Terminology (cont.)

Terminology	New Construction	Existing Building	Previously Commissioned	Not Previously Commissioned
Commissioning	✓			
Retrocommissioning		✓		✓
Recommissioning		✓	✓	

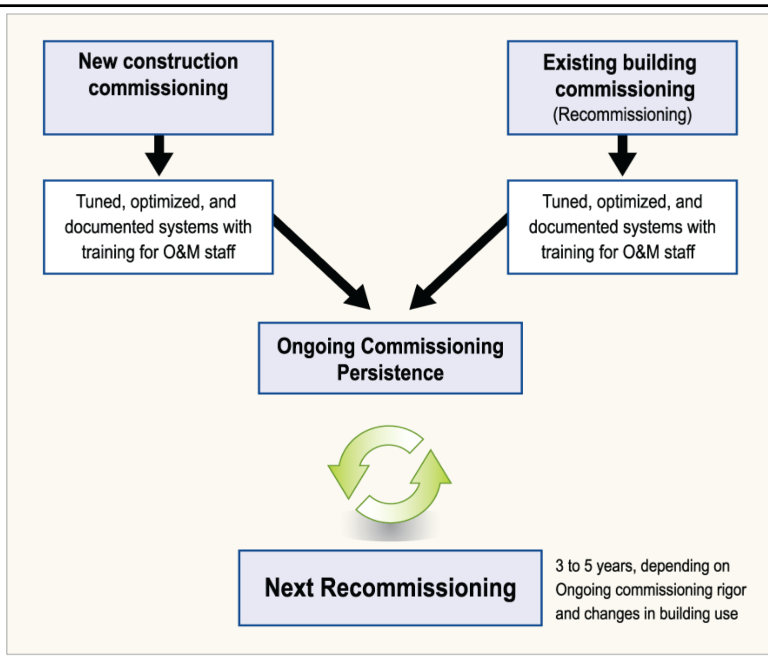
Service	Operations and Maintenance (O&M) Improvements	No-Cost / Low-Cost Savings Opportunities	Capital Retrofit Savings Opportunities
Recommissioning (RCx)	Primary	Primary	Secondary
Energy Audit	Secondary	Primary	Primary

Adapted from: Jim Poulos. *"Existing Building Commissioning,"* ASHRAE Journal, Sept. 2007, pp. 66-78.

Table 3: Differences between an energy audit and an O&M assessment.

Energy Audit	O&M Assessment
Emphasizes investigating existing building systems for equipment replacement (retrofit) opportunities leading to energy cost savings	Emphasizes investigating existing building systems to identify low-cost O&M improvements leading to energy cost savings
Seldom includes functional testing of present building systems	Generally includes some degree of functional testing of present building systems
Generally performed by an outside consultant	Generally performed by an outside consultant
May include building simulation models	Rarely includes building simulation models
Results in a list of energy conservation retrofit measures	Results in a master list of O&M improvements
Typical recommendations are time consuming and expensive to implement	Typical recommendations are fast and inexpensive to implement
Typical projects provide attractive rates of return sometimes more than 30% with a payback often greater than three years	Typical paybacks are estimated at less than two years and often less than one year
Generally requires an outside contractor to implement equipment replacements	In-house staff can often implement many O&M improvements

Adapted from: PECI. *"Operation and Maintenance Assessments – A Best Practice for Energy-Efficient Building Operations"*, O&M Best Practices Series, funded by the US EPA and US DOE, September 1999.



RCx Provider Tasks

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Task	Cx	RCx
Design review	✓	
Construction observations	✓	
Issues/findings log	✓	✓
System testing and issues resolution	✓	✓
Documentation update	✓	✓
Operator training	✓	✓

Why Recommission?

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- Owners and managers do not typically have fully functional building systems at the time of initial occupancy
- Owners and managers face an increasing number of performance problems
- Buildings are more complex
- Current use of facilities may be quite different from that envisioned at the time of their design
- Building systems are becoming increasingly specialized and integrated
- Comfort problems are often the reason RCx projects are conducted

Benefits of Recommissioning (RCx)

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- Provides a healthy and comfortable working environment for occupants
- The owner obtains equipment and systems that function properly based on current facility requirement (CFR)
- Reduces energy, operating and maintenance costs (improves net operating income)
- Reduces the chance of premature equipment failure
- Helps to compile accurate and comprehensive building documentation, thus reducing troubleshooting time
- Trains and educates building owners, managers, operators and users

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RCx's Energy Savings Potential

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- Most projects result in energy savings of 5 to 15% after the implementation of low-cost RCx measures
- Cost recovery periods of 2 years or less are common

SEE ALSO *RETRO-COMMISSIONING'S GREATEST HITS,* PRESENTED AT ICEBO 2001 BY TUDI HAASL

www.canmetenergy.nrcan.gc.ca/recommissioning_resources.html

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Non-Energy Benefits (NEBs) and Non-Energy Impacts (NEIs)

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- Fewer premature breakdowns
  - Reliability
  - Ongoing operating costs
- Fewer comfort-related complaints
- Improved Indoor Environmental Quality (IEQ)
- Fewer production losses
- Improved O&M documentation and practices

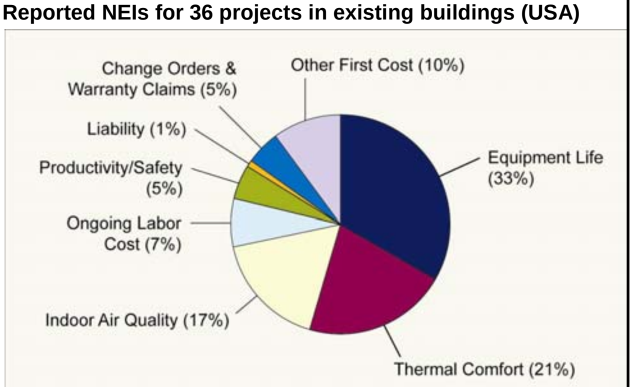
Recent Research on the Value of NEIs/NEBs in Existing Buildings

Median Value:
$1.94 / m² or $0.18 / ft²

Range:
$1.08 - $4.84 / m²
$0.10 - $0.45 / ft²

This can be VERY significant when contrasted with the median energy savings potential of 15%

Reported NEIs for 36 projects in existing buildings (USA)



Source: Lawrence Berkeley National Laboratory, "The Cost Effectiveness of Commercial-Buildings Commissioning," December 2004.

For typical commercial buildings: ≈ $1.61 to $3.23 / m² ≈ $0.15 to $0.30 / ft²

Additional Quantifying Data on NEBs and NEIs

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- Non-energy benefits include, among other things, increased productivity, reliability and tenant satisfaction. This is what participant surveys tell us about the design and marketing of commercial programs
  - Dennis Pearson, Seattle City Light
  - Lisa A. Skumatz, Skumatz Economic Research Associates, Inc.
- Published at the 2002 ACEEE Summer Study on Energy Efficiency in Buildings
- Further developed at the 2004 ACEEE Summer Study

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What Does it Typically Cost?

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- ~$3,000 to conceive and design a typical project
- $1.08 to $10.76 / m^2 or $0.10 to $1.00 / ft^2 for the total RCx process, depending on:
  - Number of systems
  - System complexity
  - Number of zones
  - Data logger rentals
  - Owner requirements
  - Subcontractor requirements
  - Involvement in implementation
  - Owner involvement

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Examples of RCx Costs

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Description	Value or Range
Total RCx Cost	\$1.08 to \$10.76 / m^2 \$0.10 to \$1.00 / ft^2
Provider Fee (% of total cost)	35% to 71%
Typical Cost Allocation	
Planning and Inspection	69%
Implementation	27%
Audit, Reporting	4%
Typical Cost Recovery Period	0.2 to 2.1 years

Adapted from: Evan Mills *et al.*, "The Cost-Effectiveness of Commercial-Buildings Commissioning", Lawrence Berkeley National Laboratory, LBNL – 56637 (Rev.), December 15, 2004, 99 pp.

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Phase 1: Planning – Part 1: Pre-screening

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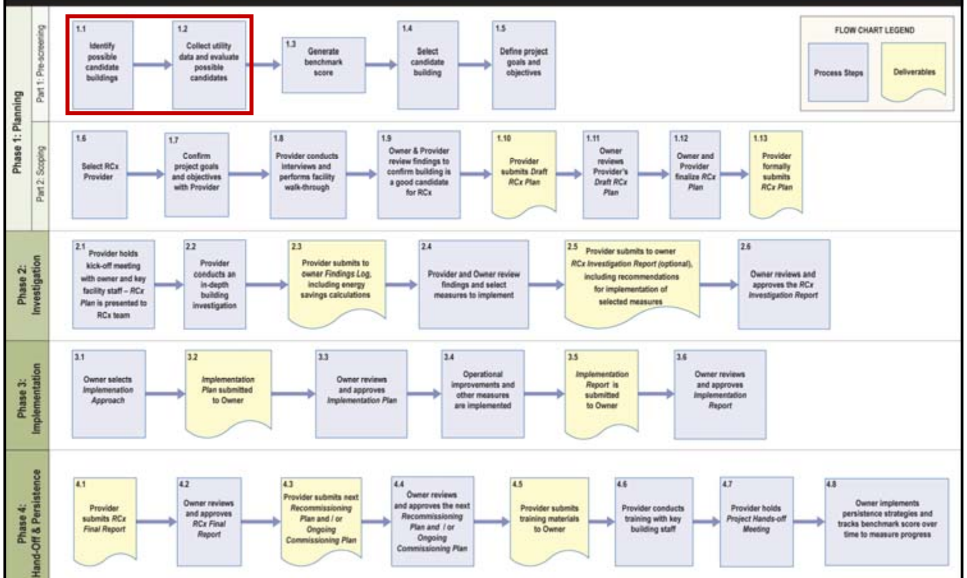
Phase 1: Planning – Part 1: Pre-screening

- Building Portfolio Prioritization
- Utility Bill Analysis
- Benchmarking

Recommissioning (RCx) Process



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RCx Planning Phase - Screening

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- Select good building candidates for RCx
- Appropriate building characteristics:
  - Existing medium to large commercial and institutional buildings
  - Buildings with existing Direct Digital Controls (DDC) or Energy Management Control System (EMCS) down to zone level
  - High energy consumption (J/m^2 or Btu/ft^2) - optional
  - Proactive management philosophy
  - Mechanical equipment in relatively good condition and not at end-of-life
  - At least 75% occupancy rate

Building Size and Age of Equipment

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- Smaller buildings are sometimes less cost-effective to recommission
  - May need more abbreviated process
- But small buildings with complex HVAC equipment are good candidates for RCx
  - Laboratory with VAV supply, fume hoods, pressure relationships between adjacent areas
- Buildings with old equipment that are near end-of-life
  - May be more appropriate to replace equipment first (take advantage of utility rebate programs)
  - Then recommission the building with new equipment installed to ensure optimization with rest of the systems

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Prioritizing a Portfolio of Buildings

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- Quick way to eliminate buildings that are unsuitable for a scoping study, saving you time and money
- Things to consider when prioritizing:
  - Size of building
  - Equipment age
  - Equipment configuration
  - Building maintenance practices
  - Interest of owner and operational staff in participating
  - Utility expenditures
    - Energy costs
    - Water costs

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Prioritizing (con't)

- Control Systems:
  - HVAC control equipment that won't stay calibrated (manual, pneumatic, and electro-magnetic controls) are not the best choice for a RCx process
  - DDC system can be used to monitor and troubleshoot system operation
- Building Maintenance Practices:
  - Equipment that has not been regularly maintained will reduce effectiveness of the process

Prioritizing (con't)

- Operational Staff or Service Contractor Buy-in:
  - Staff and or service contractors must be capable and willing (or directed) to assist and learn from the process
  - Good working relationship with outside contractors
- Owner Interest and Owner's Champion:
  - Owner's buy-in to the process is crucial for success

Screening: Owner's Obligations

- Owner responsibility for operating expenses (ideal)
- Willingness to commit at least 20 hours of staff time
- No planned major renovations/retrofits in the next 3 years
- No known barriers to implementing RCx measures
- Willingness to release energy bills for the last 12 months (ideally for the last 36 months)
- Ability to commit funding to implement selected measures

Necessary Documentation

- Utility data – at least 12 months
- Control drawings with full points list
- Sequence of operations
- Set of as-built drawings
  - Mechanical
  - Plumbing
  - Electrical
  - Architectural drawings
- Test and Balance (TAB) report(s)
- Past energy conservation reports
- Original equipment submittals

Contract Documents
Drawings, Specs, and Shop Drawings

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- Complete specification book
- Shop drawings - copies or access to:
  – Controls
  – Major energy users
  – Terminal equipment
  – Duct and piping fabrication

Reports Gain from the Effort of Others

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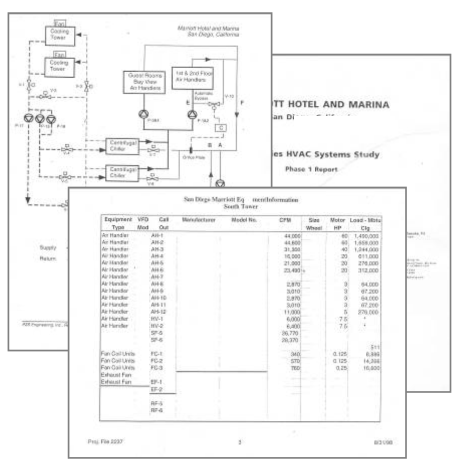
- Facilities HVAC Systems Study
  – **Descriptions**
    - ➢Facilities
    - ➢Systems
    - ➢Energy Use
  – **Data**
    - ➢Equipment schedules
    - ➢Space functions
  – **Recommendations**



What Do You Do With All of This?

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- Get a feel for "the lay of the land", designer's intent
- Begin to understand integration issues
- Identify major energy users
- Understand RCx costs:

  Good documentation = Less effort

  - Less research
  - Less development
- Identify "Typical of all …" issues

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Utility Consumption Analysis

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- Can provide significant insight and direction for RCx efforts
  - Normalized Consumption
  - Daily consumption patterns
  - Benchmarking

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A Good Spreadsheet Application

Month	Days In Calendar Month	Date Of Reading	Days In Billing Period	Usage - kWh	Cost Including Tax And Demand - $	Nominal Electrical Rate - $/kWh	Average Daily Usage For The Billing Period - kWh per Average Day	Normalized Usage For The Calendar Month - kWh	Average Daily Usage For The Calendar Month - kWh per Average Day	Average Daily Cost For The Calendar Month - $ per Average Day
April	30	05/13/00	32	25,760	$3,127.00	$0.121	805	24,036	801	$97.26
May	31	06/12/00	30	27,840	$4,151.00	$0.149	928	27,169	876	$130.68
June	30	07/14/00	32	30,240	$4,508.00	$0.149	945	28,146	938	$139.86
July	31	08/12/00	29	27,040	$4,032.00	$0.149	932	29,081	938	$139.88
August	31	09/11/00	30	29,280	$4,365.00	$0.149	976	29,733	959	$142.98
September	30	10/10/00	29	30,080	$4,484.00	$0.149	1,037	30,444	1,015	$151.27
October	31	11/12/00	33	30,720	$4,057.00	$0.132	931	29,922	965	$127.47
November	30	12/11/00	29	23,520	$2,409.00	$0.102	811	25,770	859	$87.98
December	31	01/12/01	32	24,160	$2,381.00	$0.099	755	24,021	775	$76.37
January	31	02/11/01	30	24,800	$2,285.00	$0.092	827	24,767	799	$73.61
February	28	03/13/01	30	24,000	$2,212.00	$0.092	800	22,693	810	$74.70
March	31	04/14/01	32	25,760	$2,373.00	$0.092	805	24,890	803	$73.96

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A Good Spreadsheet Application

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1 - This

2 - Divided by this

3 - Yields this

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A Good Spreadsheet Application

Month	Days In Calendar Month	Date Of Reading	Days In Billing Period	Usage - kWh	Cost Including Tax And Demand - $	Nominal Electrical Rate - $/kWh	Average Daily Usage For The Billing ... Average Day	Normalized Usage For The Calendar Month - kWh	Average Daily Usage For The Calendar Month - kWh per Average Day	Average Daily Cost For The Calendar Month - $ per Average Day
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June	30	07/14/00	32	30,240	$4,508.00	$0.149	945	28,146	938	$139.86
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	938	$139.88
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	959	$142.98
September	30	10/10/00	29	30,080	$4,484.00	$0.149	1,037	30,444	1,015	$151.27
October	31	11/12/00	33	30,720	$4,057.00	$0.132	931	29,922	965	$127.47
November	30	12/11/00	29	23,520	$2,409.00	$0.102	811	25,770	859	$87.98
December	31	01/12/01	32	24,160	$2,381.00	$0.099	755	24,021	775	$76.37
January	31	02/11/01	30	24,800	$2,285.00	$0.092	827	24,767	799	$73.61
February	28	03/13/01	30	24,000	$2,212.00	$0.092	800	22,693	810	$74.70
March	31	04/14/01	32	25,760	$2,373.00	$0.092	805	24,890	803	$73.96

1 - This many days
2 - At this rate
3 - Plus this many… minus this many days
4 - At this rate
5 - Yields this

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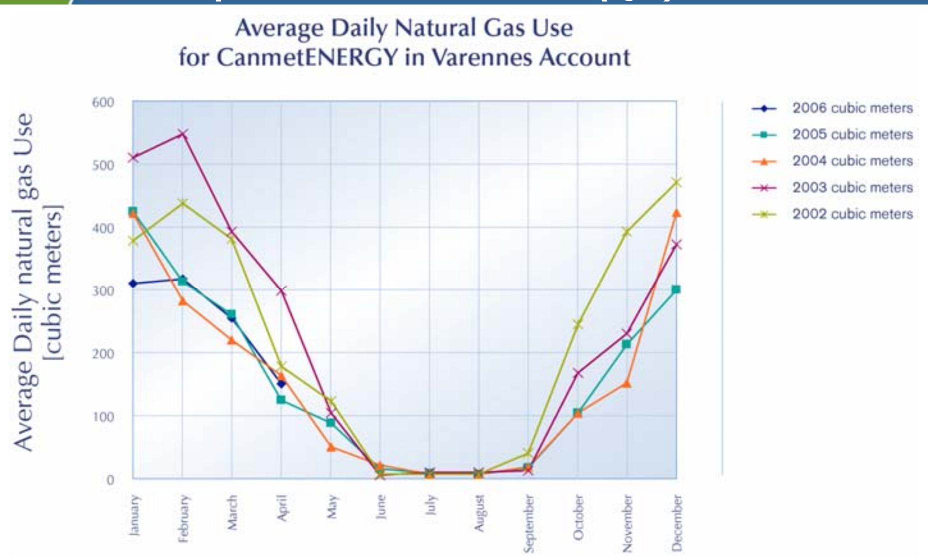
Normalized Natural Gas Consumption
Example: CanmetENERGY (QC)



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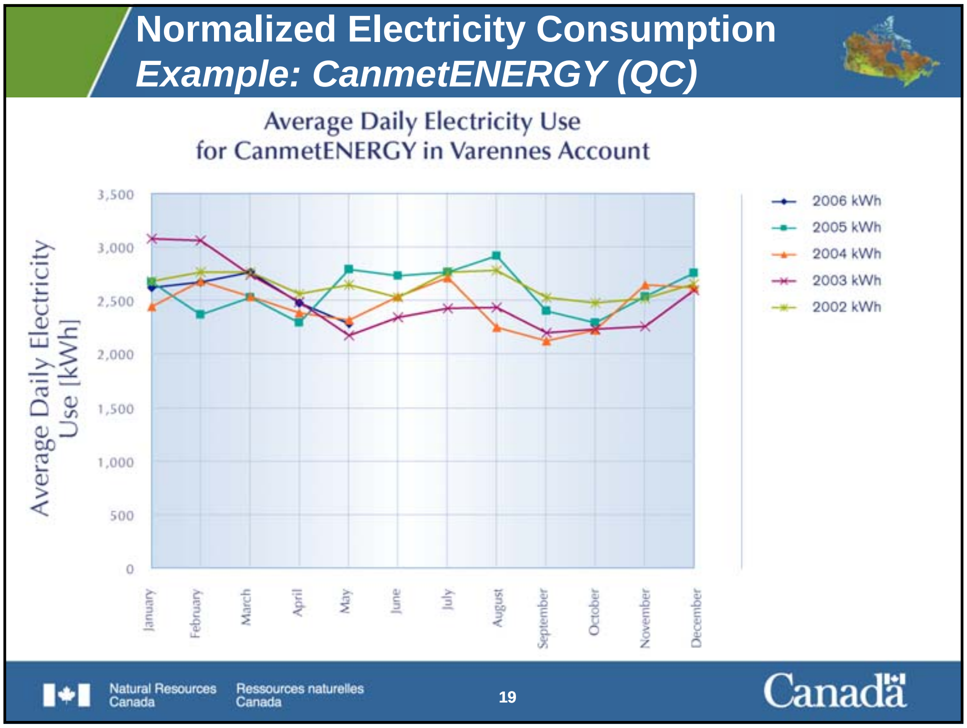
Normalized Electricity Consumption
Example: CanmetENERGY (QC)
Average Daily Electricity Use
for CanmetENERGY in Varennes Account
Average Daily Electricity Use [kWh]
3,500
3,000
2,500
2,000
1,500
1,000
500
0
January
February
March
April
May
June
July
August
September
October
November
December
2006 kWh
2005 kWh
2004 kWh
2003 kWh
2002 kWh
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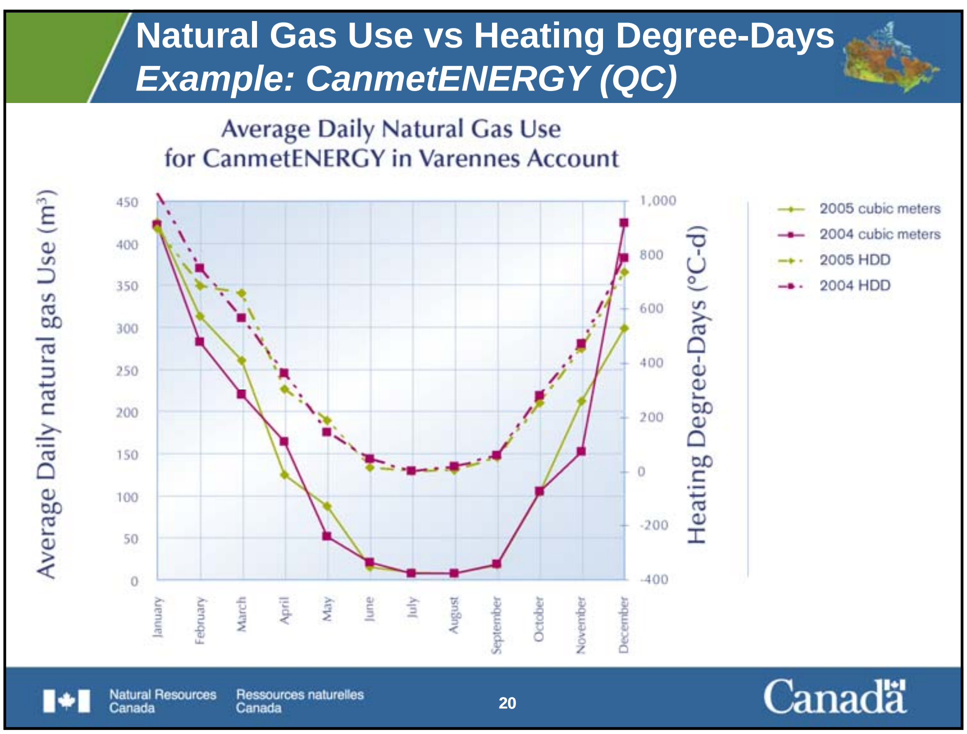
Natural Gas Use vs Heating Degree-Days
Example: CanmetENERGY (QC)
Average Daily Natural Gas Use
for CanmetENERGY in Varennes Account
Average Daily natural gas Use (m³)
Heating Degree-Days (°C-d)
450
400
350
300
250
200
150
100
50
0
1,000
800
600
400
200
0
-200
-400
January
February
March
April
May
June
July
August
September
October
November
December
2005 cubic meters
2004 cubic meters
2005 HDD
2004 HDD
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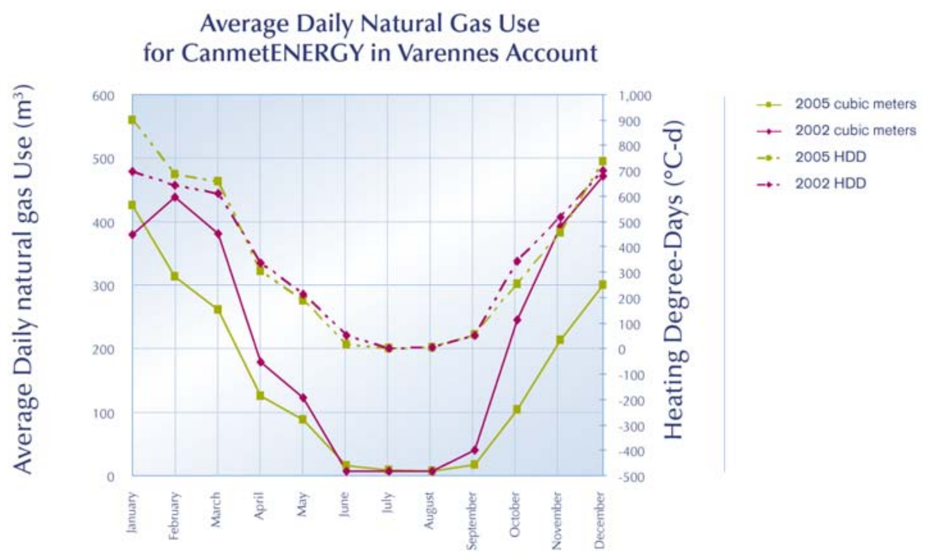
Natural Gas Use vs Heating Degree-Days
Example: CanmetENERGY (QC)



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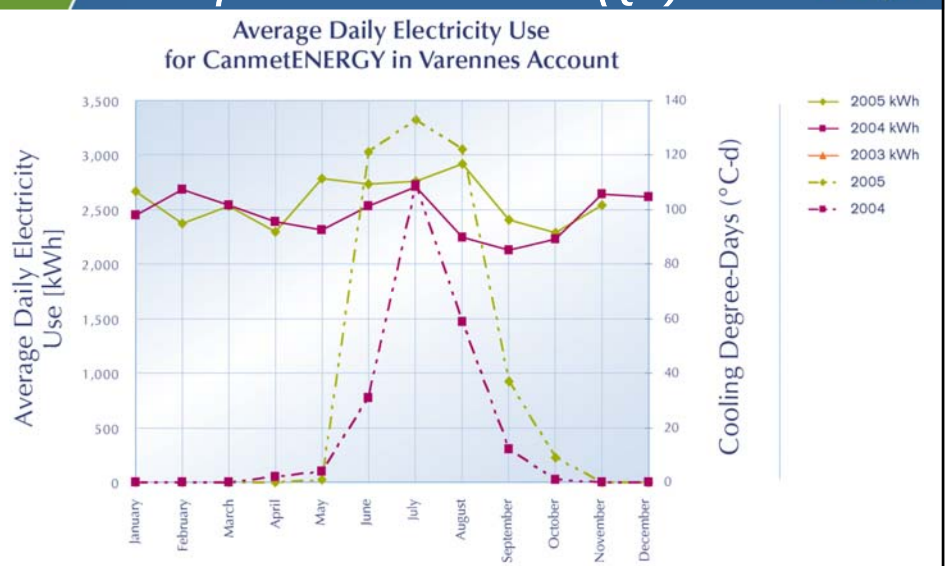
Electricity Use vs Cooling Degree-Days
Example: CanmetENERGY (QC)



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More Useful Utility Data

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- Interval utility data (i.e. 15 minute data) can be extremely useful in identifying operational issues.
  - Can be used to identify base load during unoccupied conditions
  - Can be used to identify operational problems during normal building operating hours

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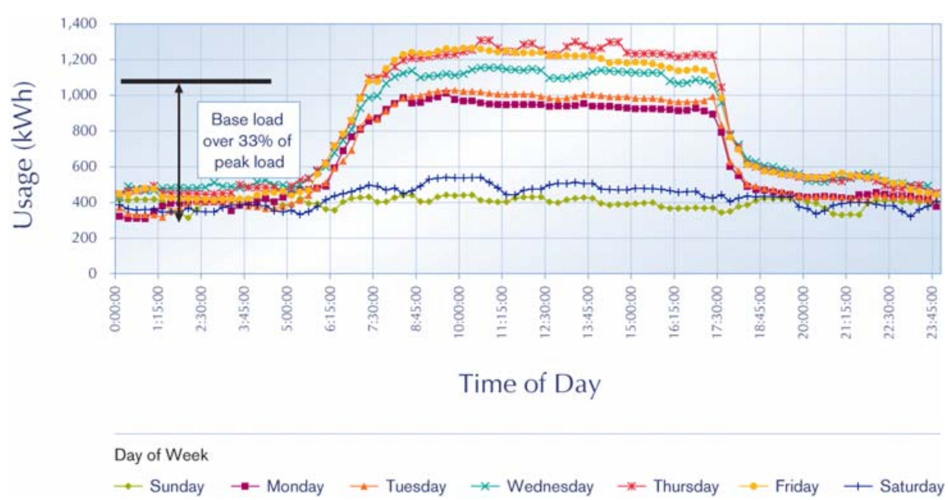
Electricity Load Profile for Typical January Week (2003)



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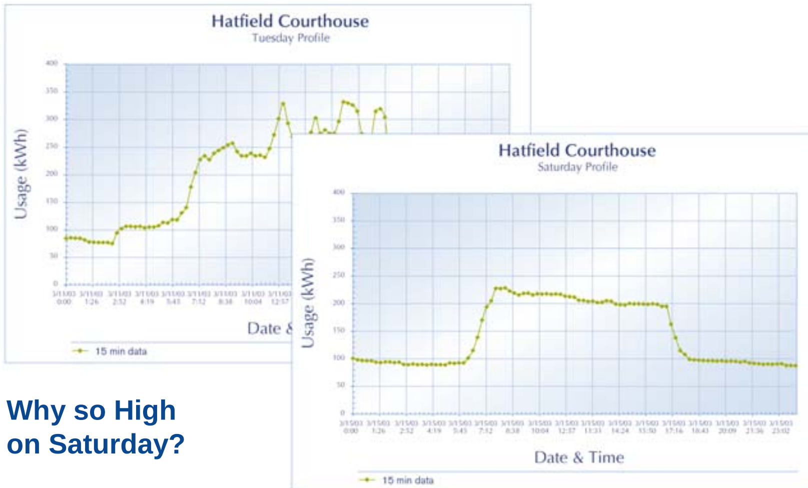
Using 15-Minute Utility Data
Different Days – Same Season



Why so High on Saturday?

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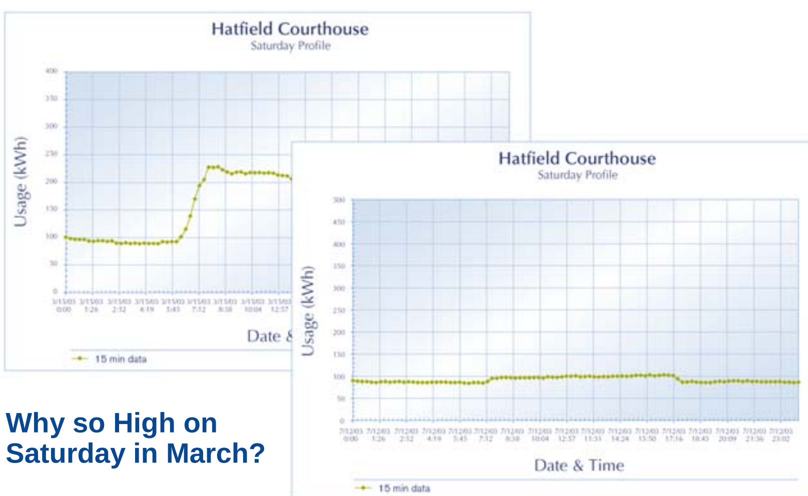
Using 15-Minute Utility Data
Same Day – Different Season



Why so High on Saturday in March?

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Utility Bill Analysis

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- Use rate schedule for building to determine actual energy and power costs when calculating savings
  - Use a combined energy/demand cost when a measure saves both demand and energy
  - Use an energy-only cost when a measure saves energy but not demand
  - May need to adjust calculations to reflect actual time-of-use (i.e. on-peak; mid-peak; off-peak charges)
- In some situations, it may be possible to change from one rate schedule to another depending on actual building load and system modifications implemented.
  - The charges associated with the proposed rate schedule should be used in savings calculations

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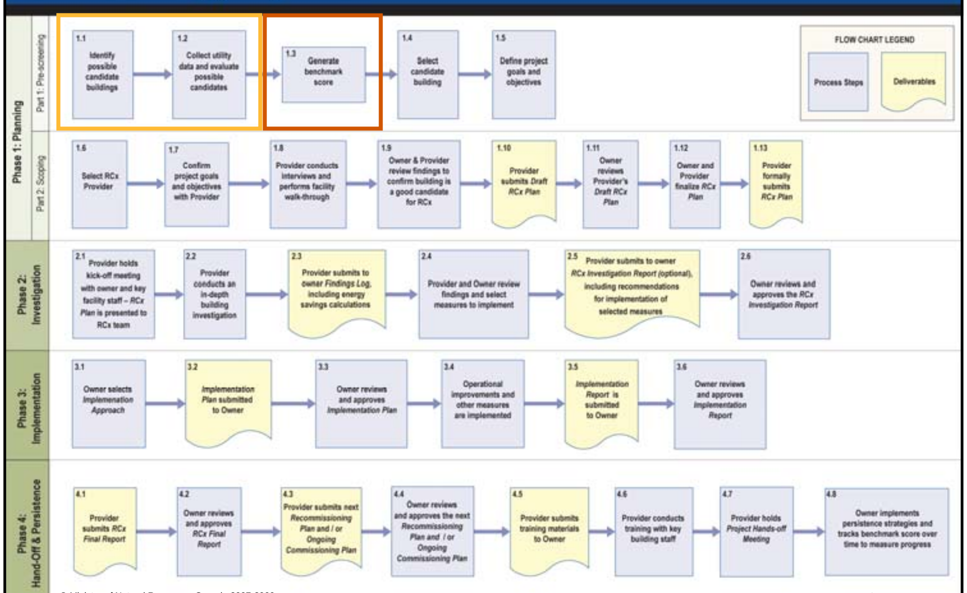
Recommissioning (RCx) Process



 www.canmetenergy.nrcan.gc.ca

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Benchmarking Looking at Energy Usage

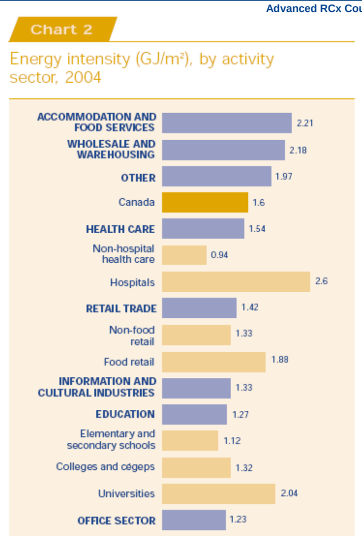
- The annual Energy Use Index (EUI) is probably the most common benchmark used to make comparisons between buildings
  - Combine all utilities to a common unit to get an overall energy usage per building area (J/m^2 or Btu/ft^2)
  - Best to compare buildings of similar use-type and climatic conditions
- Depending on building type, other benchmarking parameters may be more appropriate
  - Occupants (students for schools; patients for hospitals)
  - Process (# of meals served for restaurants)

NOTE: Those parameters must be impact factors

Benchmarking

- Energy intensity data are from: *Commercial and Institutional Consumption of Energy Survey 2004)*

www.canmetenergy.nrcan.gc.ca/recommissioning_benchmarking.html



End Use Data for Benchmarking

Chart 4

Energy intensity (GJ/m²) of non-food retail establishments, by region, 2004

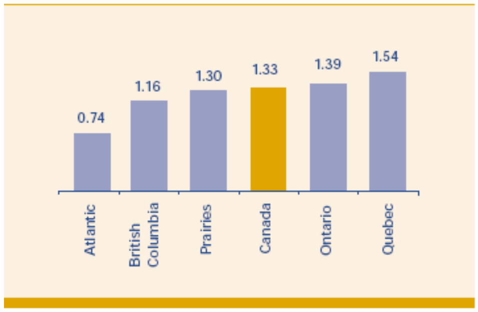
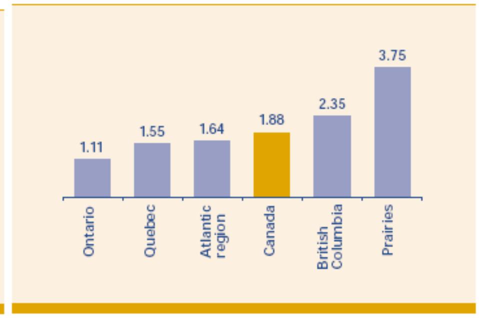


Chart 5

Energy intensity (GJ/m²) of food retail establishments, by region, 2004



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End Use Data for Benchmarking

Chart 6

Energy intensity (GJ/m² of colleges and cégeps, by region, 2004

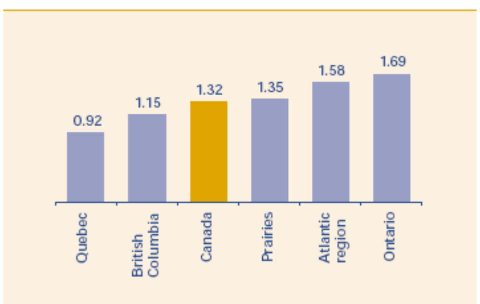
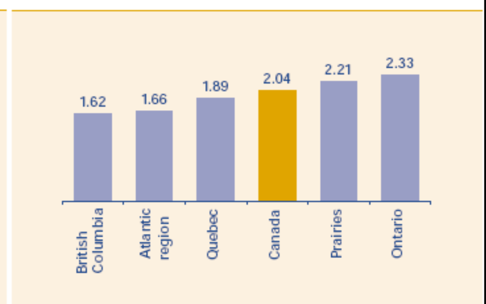


Chart 7

Energy intensity (GJ/m²) of universities, by region, 2004



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End Use Data for Benchmarking

Chart 8

Energy intensity (GJ/m²) of non-hospital health care establishments, by region, 2004

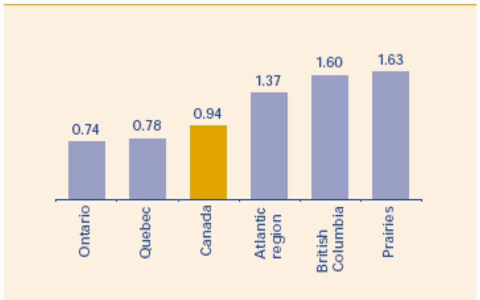
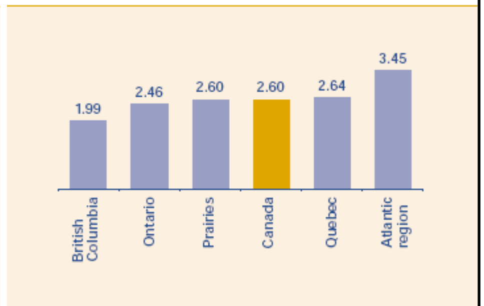


Chart 9

Energy intensity (GJ/m²) of hospitals, by region, 2004



Benchmarking Tools

- There are many for-purchase benchmarking tools on the market that can normalize data on many parameters, including weather, occupancy, process load, etc.

www.canmetenergy.nrcan.gc.ca/building_energy_software_tools.html

Benchmarking Tools

Advanced RCx Course

- One free benchmarking tool is the EnergyStar Portfolio Manager program.
  - Normalizes energy usage based on weather data
  - Weather information for most major Canadian cities:
    - Calgary
    - Edmonton
    - Halifax
    - Montréal
    - Ottawa
    - Québec
    - Regina
    - Toronto
    - Vancouver
    - Winnipeg
  - Portfolio Manager generates an Energy Use Index (EUI) for the building, but not an accurate EnergyStar rating because there are no buildings from Canada in the database

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Benchmarking with energy ®

Advanced RCx Course

- How does it work?
  - Building performance assessment
    - Not available since no buildings in the database
  - Energy use assessment does take into account:
    - Weather
    - Size
    - Location
    - Operating characteristics
- Why do it?
  - Quick reality check for scoping
  - Tracking tool for persistence

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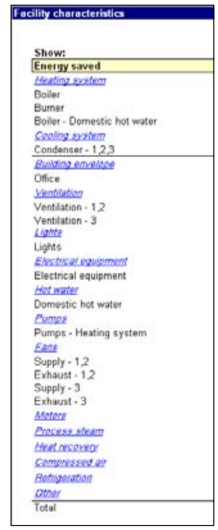
RETScreen Clean Energy Project Analysis Software for RCx projects

Advanced RCx Course

- RETScreen can help to:
  - Prioritize a portfolio of buildings
  - Evaluate a building's energy use intensity
  - Evaluate energy savings
  - Track persistence of savings
- For a wide range of building types (e.g. office, hospitals, schools, etc.)
- For whole building or individual rooms and zones analysis
- Applicable for ventilation, lights, electrical equipment, hot water, pumps, fans, motors, HVAC systems, etc.
- Available online for free: www.retscreen.net



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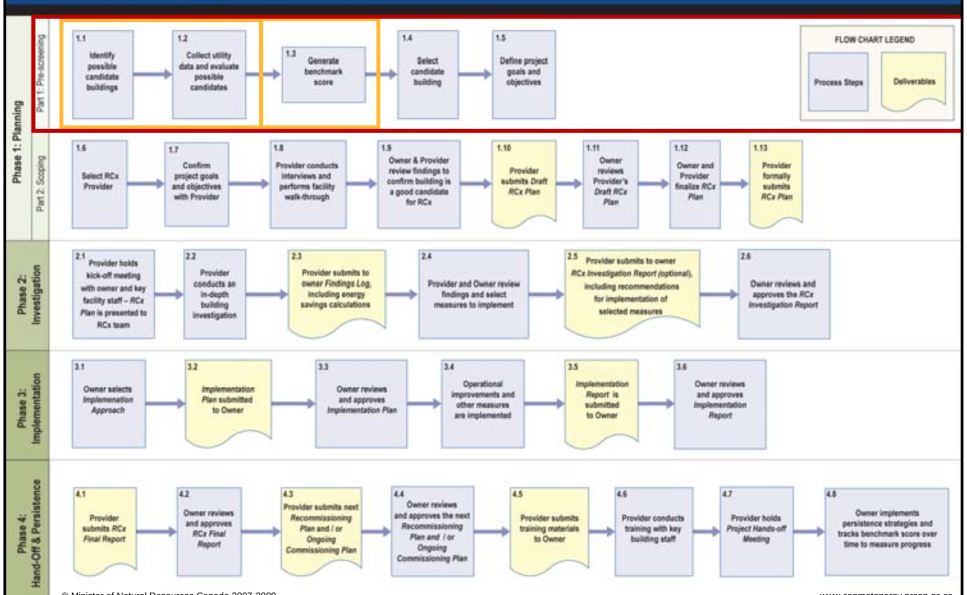
Recommissioning (RCx) Process



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Building Operation Optimization

Advanced Recommissioning (RCx) Course

Phase 1: Planning – Part 2: Scoping

Developed by Portland Energy Conservation, Inc.

P | E | C | I

Adapted by Natural Resources Canada's CanmetENERGY
www.canmetenergy.nrcan.gc.ca

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Phase 1: Planning – Part 2: Scoping

Advanced RCx Course

- Facility Walk-through
- Direct Digital Control (DDC) System Data Analysis
- RCx Plan

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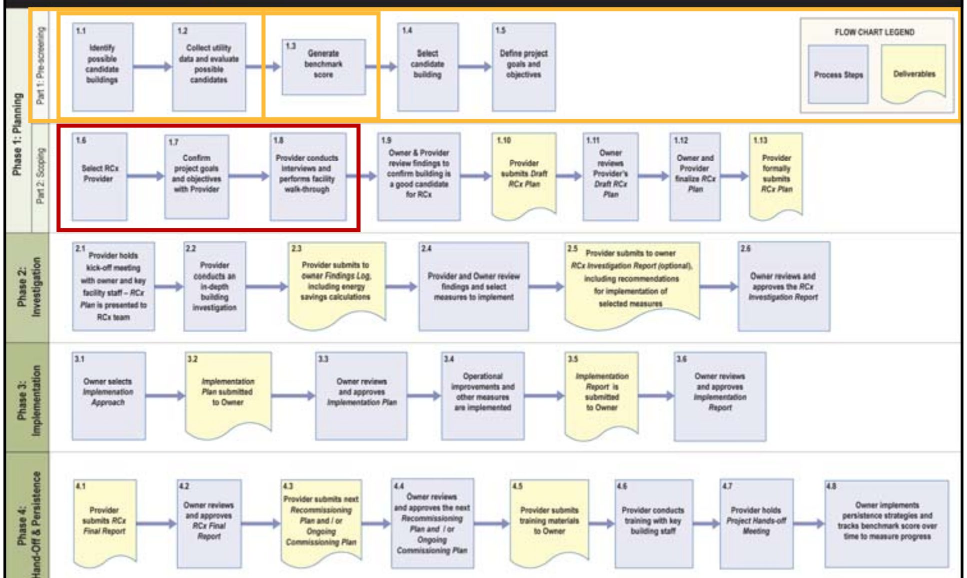
Recommissioning (RCx) Process



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Scoping: Common Low-cost Opportunities

Advanced RCx Course

- Schedules
- Setpoints / Reset Schedules
- Pumping
- Ventilation

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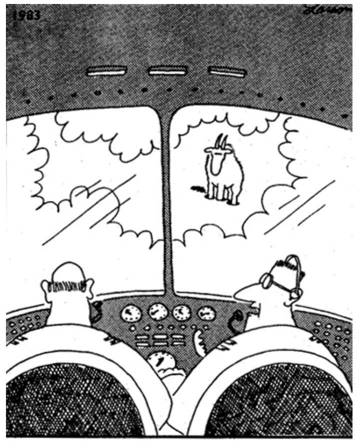
Heeding Obvious Indicators

Advanced RCx Course

- Sound
- Sight
- Touch
- Existing gauges



"Say ... what's a mountain goat doing way up here in a cloud bank?"

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Sound

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- Noise as an indicator
  - Excessive sound (usually not good), failure sign
  - Lack of sound (occasionally not good), system is off
  - Changes in sound level (cycling)

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Mechanical Noise

Advanced RCx Course

- Sometimes it's a good thing
  - Whirring
  - Humming
  - Swishing
  - Hissing
  - Short duty cycles in an off season
- And sometimes it's a bad thing
  - Grinding
  - Squealing
  - Chattering (vibration)
  - Banging
  - Long duty cycles in an off season

A secondary indicator can confirm suspicions based on what you hear

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Sight

Advanced RCx Course

- Look at what the equipment is doing
  - Does it make sense for current conditions?
  - Observe positions of valves and dampers
  - Observe general condition of equipment

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If The Cooling Coil Is Wet …

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… then the primary humidifier probably should not be adding moisture downstream of it!

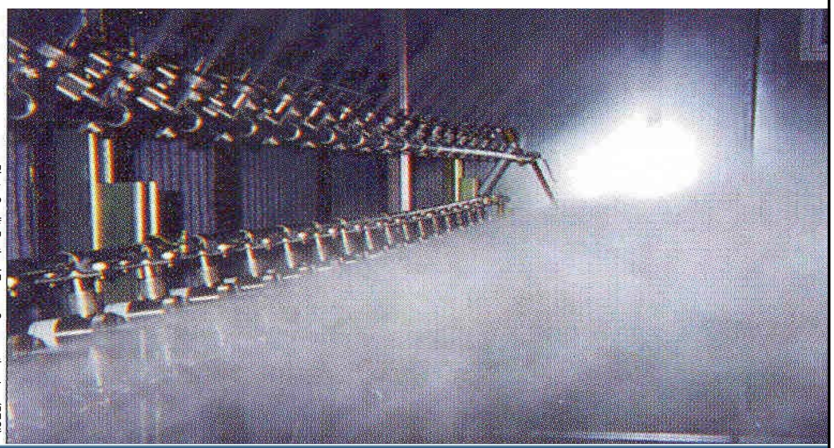

Photo Credit: Portland Energy Conversation, Inc. (PECI)

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Throttling Valve Position Can Indicate Opportunities

Advanced RCx Course

- Record the size of valve and stem position using the Flow Indicator Scale. Calculate percentage of valve opening referring to the following table

4/9 = 0.445

55% throttled (minimum)

Photo Credit: Portland Energy Conversation, Inc. (PECI).

Valve Size	2 ½	3	4	**5**	6	8	10	12
Number of Rings (valve full open)	5	5	6	**9**	10	12	18	28

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An After Hours Walk-Through…

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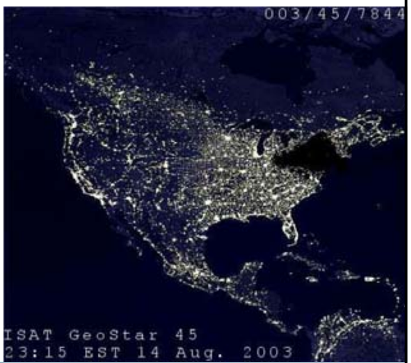
… frequently identifies unnecessary operating hours

- Things ON that could be OFF
- Lighting sweeps not working
- Round-the-clock operation vs. schedules



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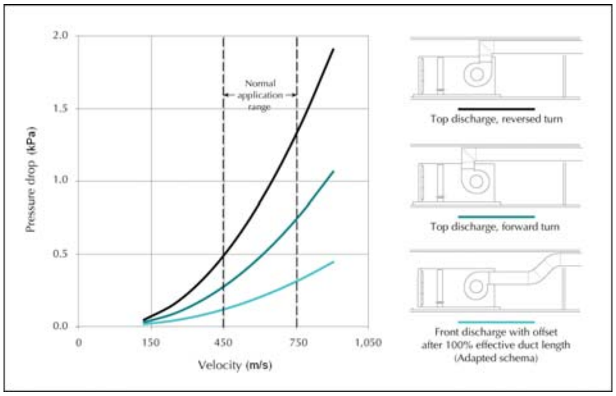
Unnecessary Pressure Drops…

Advanced RCx Course

- … Represent:
  - Wasted energy
  - Hidden capacity
- Examples
  - Throttled valves and dampers
  - Poor fitting designs



Download free Design Details from the Energy Design Resources design brief series for a closer look at the energy implications of poor fittings
www.canmetenergy.nrcan.gc.ca/energy_design_resources.html

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Metric Units

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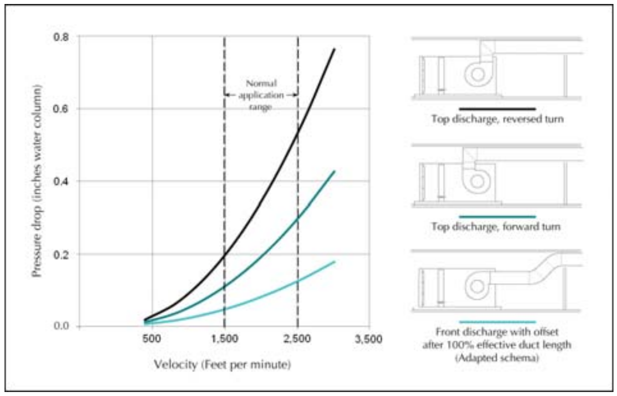
Unnecessary Pressure Drops…

Advanced RCx Course

- … Represent:
  - Wasted energy
  - Hidden capacity
- Examples
  - Throttled valves and dampers
  - Poor fitting designs

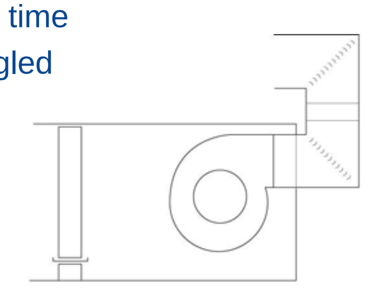


Download free Design Details from the Energy Design Resources design brief series for a closer look at the energy implications of poor fittings
www.canmetenergy.nrcan.gc.ca/energy_design_resources.html

Can't Happen… Right?

Advanced RCx Course

- Resort Spa = High profile, High revenue, High client expectation area
- Poor "As Built" Spa AHU discharge condition resulted in poor performance
  - Fan ran at full speed all of the time
  - Operating staff constantly juggled set points to maintain comfort



Touch

Advanced RCx Course

- **Touch Carefully!**
  - Is something hot or cold when it shouldn't be
  - Is something not hot or ***not cold*** when it should be

Photo Credit: Portland Energy Conversation, Inc. (PECI)

Touch Can Confirm What Your Eyes and Ears Are Telling You

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A cool day
+
100% outdoor air AHUs
+
Chilled water pump operation
+
Hot water pump operation
=
Potential simultaneous heating and cooling
+
Potential unnecessary mechanical cooling

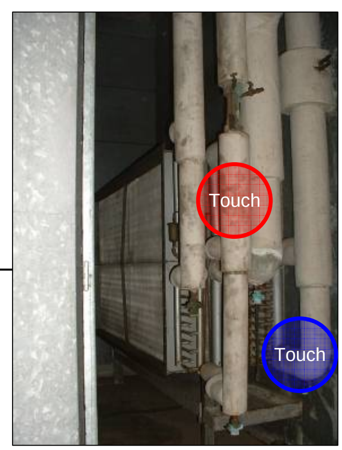

Photo Credit: Portland Energy Conversation, Inc. (PECI)

Just Because the Signal to the Valve is Fully Closed…

Advanced RCx Course

… doesn’t mean the valve is fully closed!

Photo Credit: Portland Energy Conversation, Inc. (PECI)

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If the Economizer is Not on Minimum Outdoor Air (new air)…

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… then the steam trap on the preheat coil should not be hot.

Photo Credit: Portland Energy Conversation, Inc. (PECI)

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Existing Indicators

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- Take advantage of existing instrumentation
  - Take information "with a grain of salt"
  - Cross-check with other sensory data
  - Make use of Building Automation System data logging and trending capabilities
  - Remember that sensor calibration is important

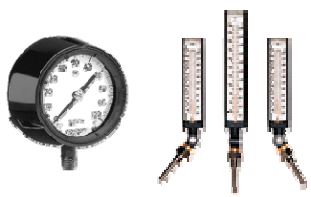

Photo Credit: Portland Energy Conversation, Inc. (PECI)

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Get A Consensus of Opinion

Advanced RCx Course

Photos Credit: Portland Energy Conversation, Inc. (PECI)

27°C VS **57°C** VS **59°C**

… the temperature is probably around 58ºC

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A Few More Fundamental Bottom Lines

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Observe the equipment in relationship to what it serves and the current conditions

Do things add up?

Boilers firing a lot	+	Summer	+	Office space, no labs	=	Unnecessary reheat load
Boilers firing a lot	+	Summer	+	Chillers fully loaded	=	Simultaneous heating and cooling
A lot of pump head	+	Short piping runs	+	No throttling	=	Excess flow
A lot of pump head	+	Short piping runs	+	throttling	=	Excess energy
High base load	=	Scheduling opportunity Simultaneous heating and cooling				

Obvious Indicators

Advanced RCx Course

- High mass flow rates
  - Large volumes of air
  - Large volumes of water
  - The sum of a lot of small flow rates
- High pressures
  - Lots of elements in series
  - Lots of filtration
  - Large distribution systems
  - Open systems with a lot of lift
- Systems or buildings with high interaction potential
  - VAV air handling
  - Variable flow pumping
- HVAC processes with the potential to simultaneously heat and cool
  - Reheat
  - Multizone
  - Double Duct
- Parasitic, standby, and auxiliary energy
  - Hot pipes, especially in warm weather
  - Systems that support primary systems

Using the Direct Digital Control (DDC) System

Advanced RCx Course

- Monitoring System Performance
  - Clues to existing problems
  - Troubleshooting aid while testing
  - Documentation aid while testing
  - Verification aid after implementation
  - Tool for ensuring persistence

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Assessing DDC Data Logging Capabilities

Advanced RCx Course

- DDC system architecture provides clues
- Control system network structure is critical to HVAC system performance
  - Controller hierarchy
  - Controller capability
    - Fully programmable vs. application specific
    - Memory
  - Communications speeds
  - Operator interfaces

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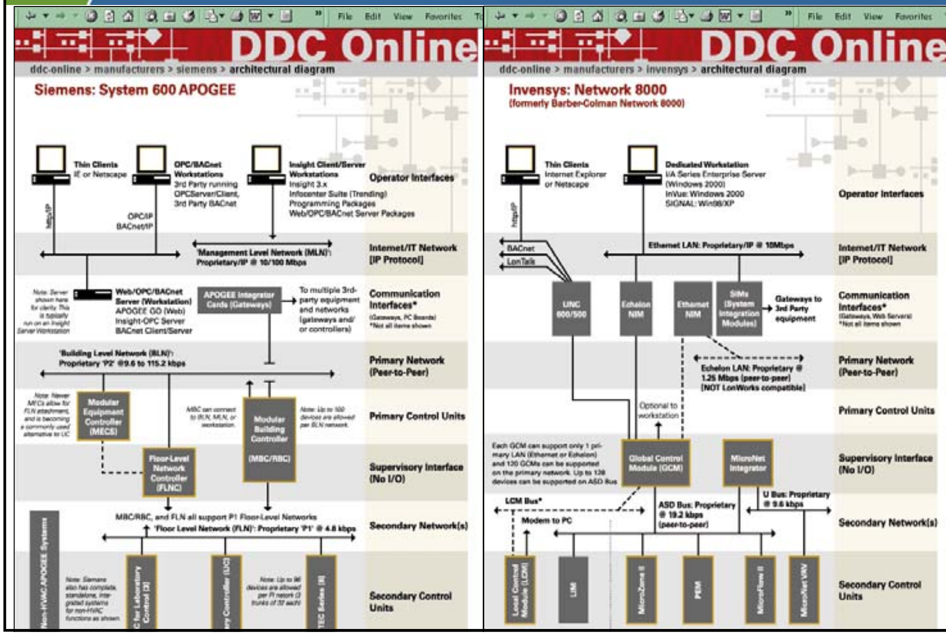
All Systems are Not the Same
Example: DDC Online (www.ddc-online.org)



Existing System Provides Clues

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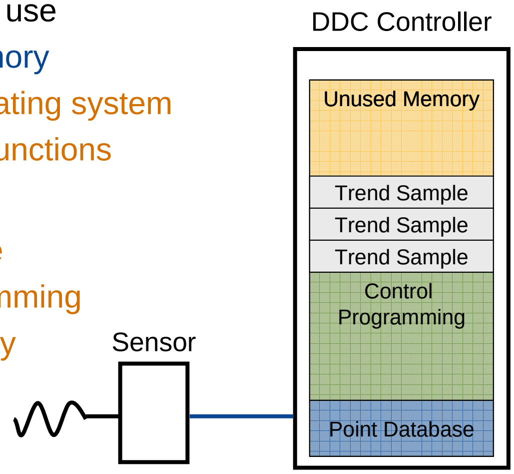
- Is the Architecture suitable?
  - Shown on the control drawings
  - Depicted in the operator work station file structure
- Is there a graphics package?
- What do the operators think?
- What is the response time?
- Do the numbers add up?

How Do DDC Systems Trend?

Advanced RCx Course

- Controller memory use
  - Non-volatile memory
    - Controller operating system
    - Basic support functions
  - Volatile memory
    - Point data base
    - Control programming
    - Unused memory available for trend data



How Do DDC Systems Trend?

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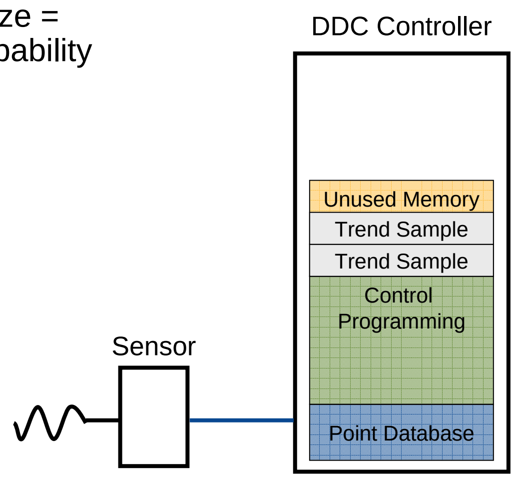
- Smaller memory size = limited trending capability



How Do DDC Systems Trend?

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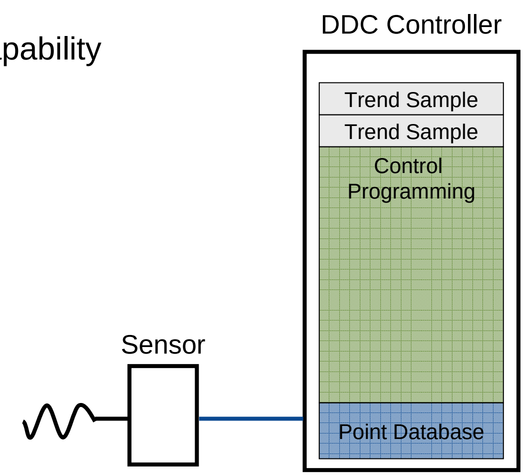
- Large program = limited trending capability



Impact of Sampling Time on Observed Data vs. What is Really Going On

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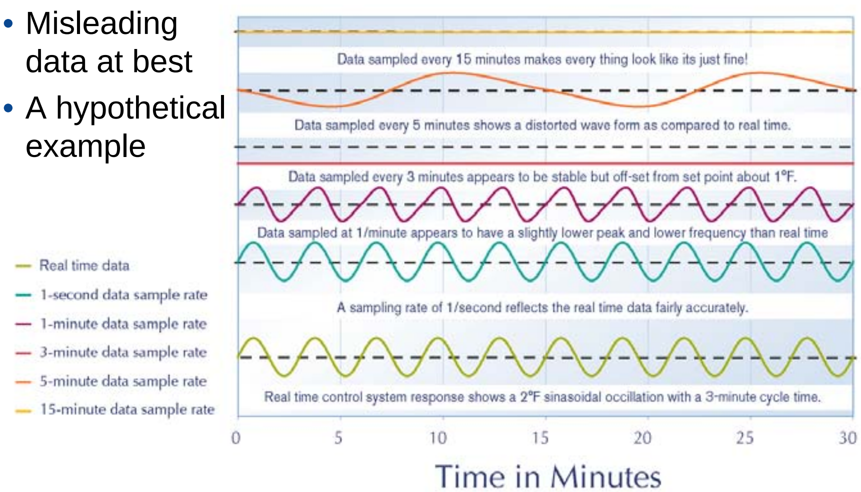
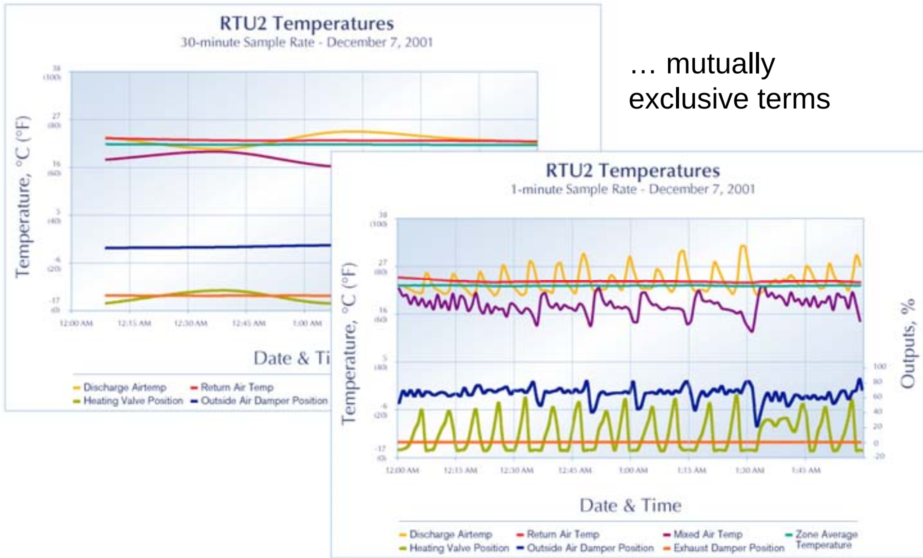
- Misleading data at best
- A hypothetical example



"Sampling Time" and "Too Fast"…



… mutually exclusive terms

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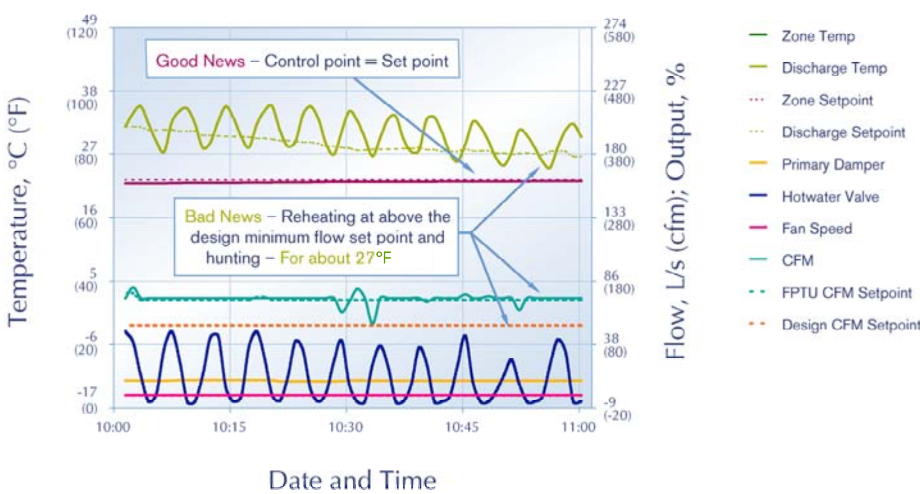
Why Does This Matter?
Example: FPTU3 (January 10, 2002)



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Wasting $50 - $100 of Energy…

… doesn't seem so bad

- Until you multiply it by 27 other terminal units doing the same thing
- Simple fixes to typical problems lead to short paybacks
  - Tune loops
  - Correct programming mistakes
  - Apply solutions to multiple similar units

There Are Also Non-Energy Benefits (NEBs)

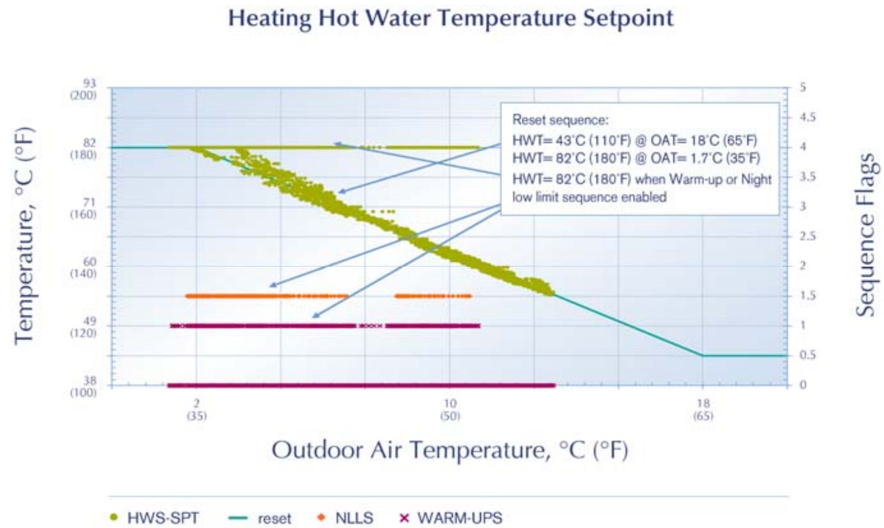
10 Cycles per hour …

… translates to 87,600 cycles per year

- Actuator design life = 60,000 cycles
- Actuator cost = $300 - $500
- Diagnosis/installation labour = 1-2 hours at $75 - $100/hr

… times 27 actuators

Sample Trend Plot



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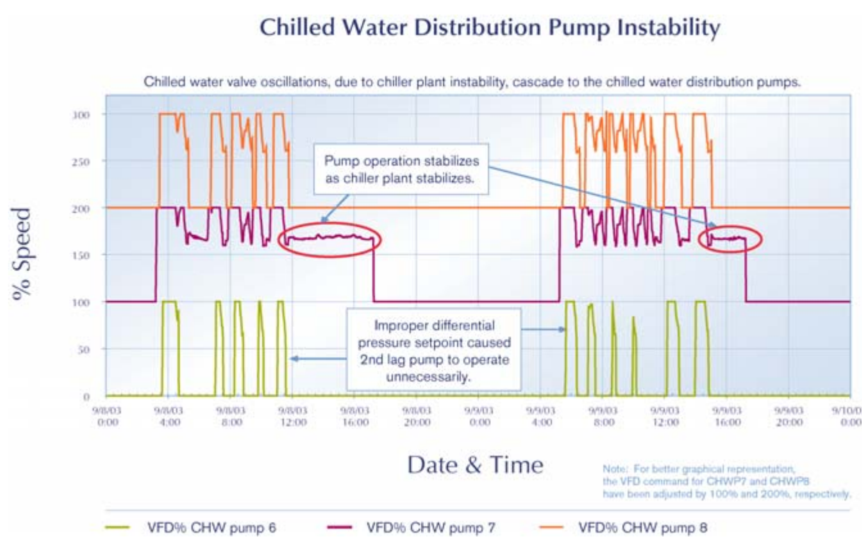
Sample Trend Plot



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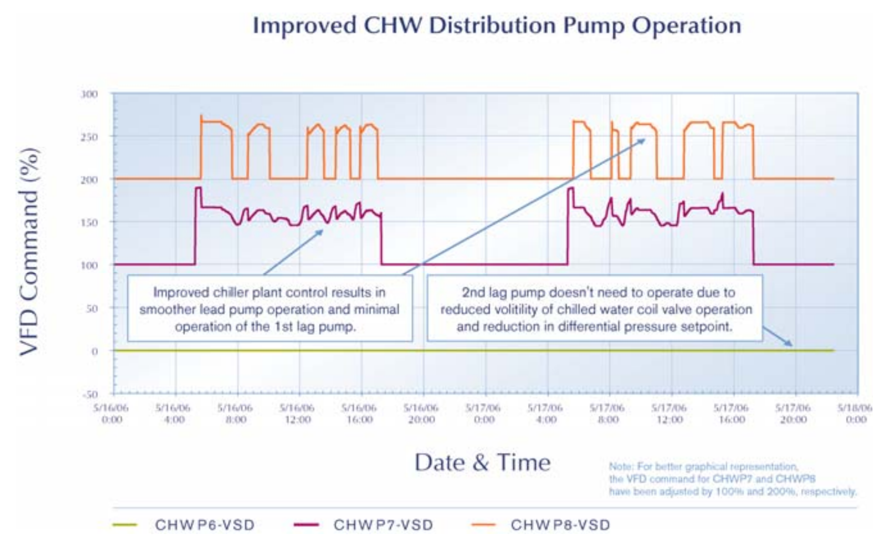
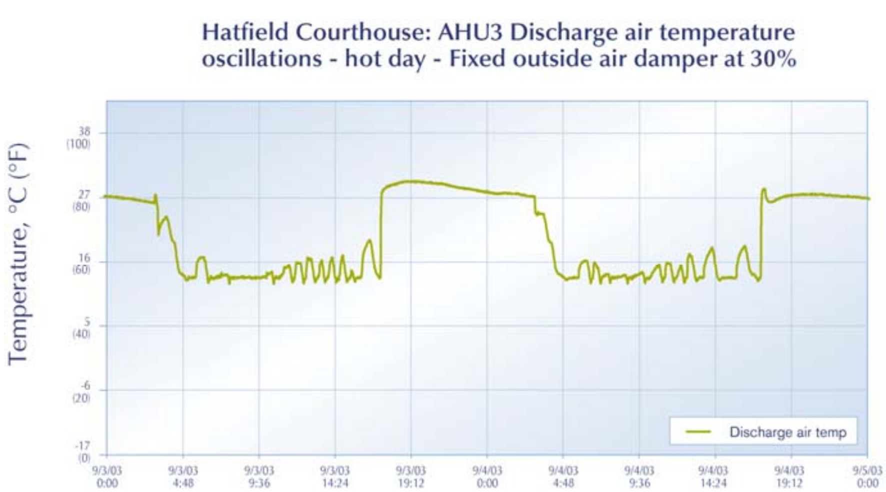
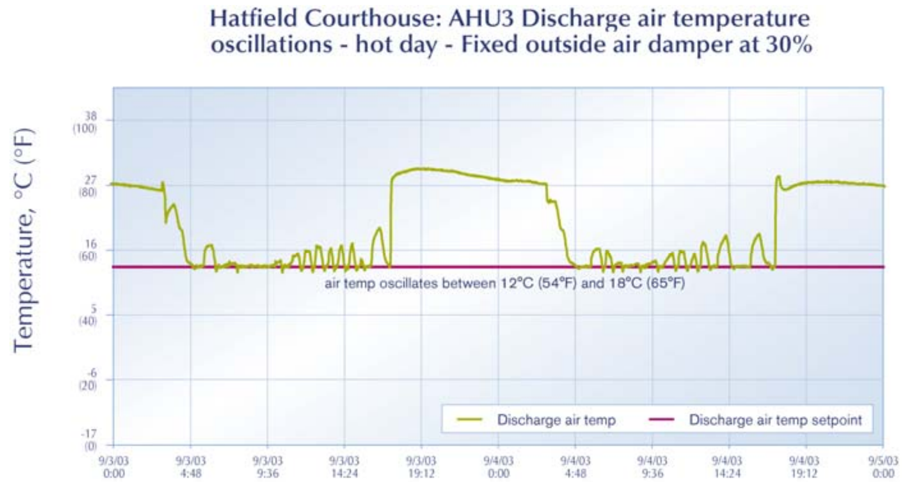
Sample Trend Plot



Trend a Single Point — *Look at it on the BAS*



Add more points to help figure out what's going on…



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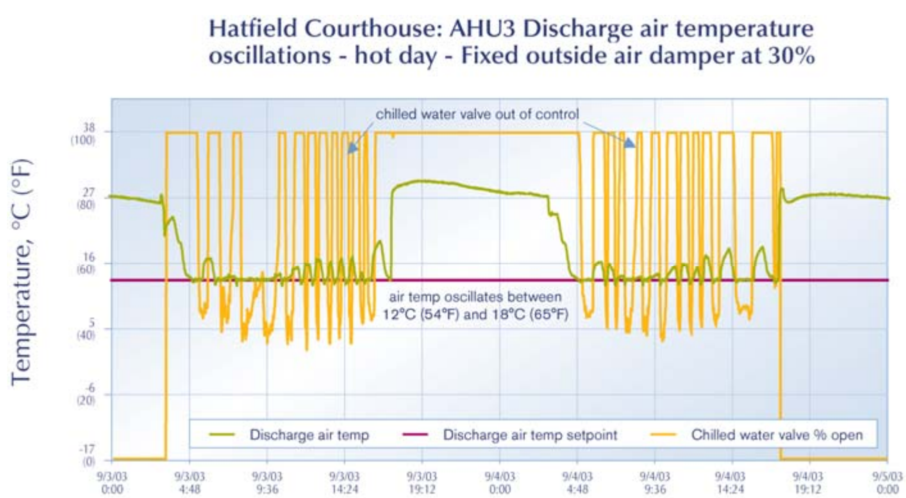
Add more points to help figure out what's going on…



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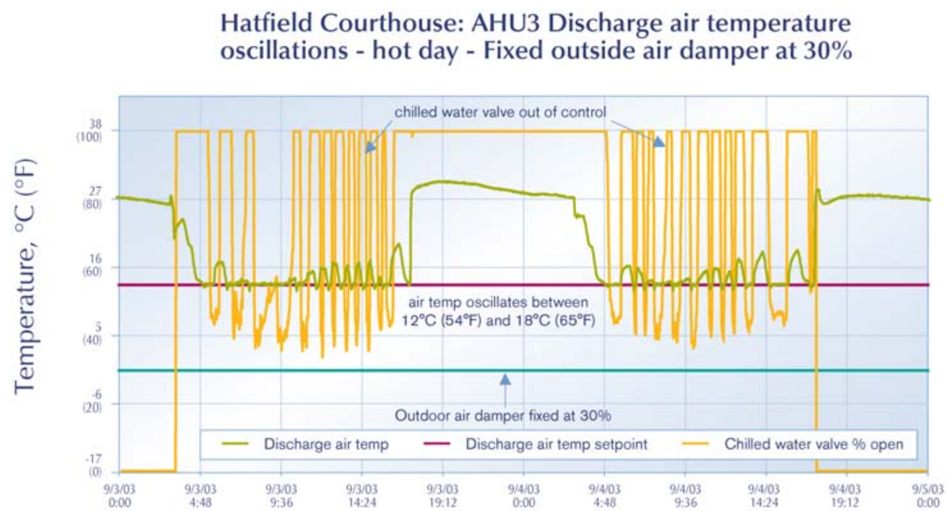
Limit of Most BAS Workstation Graphs



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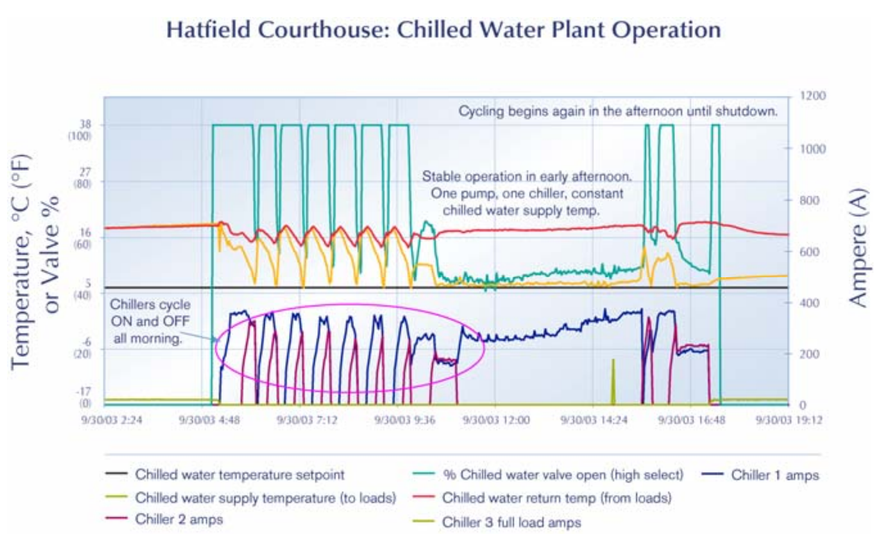
Many Points per Graph: Chilled Water Plant Instability



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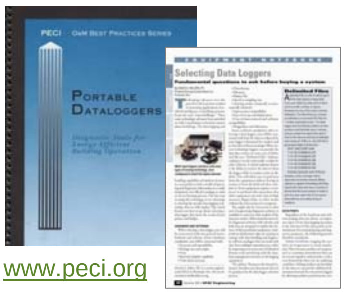
Data Logger Selection Considerations

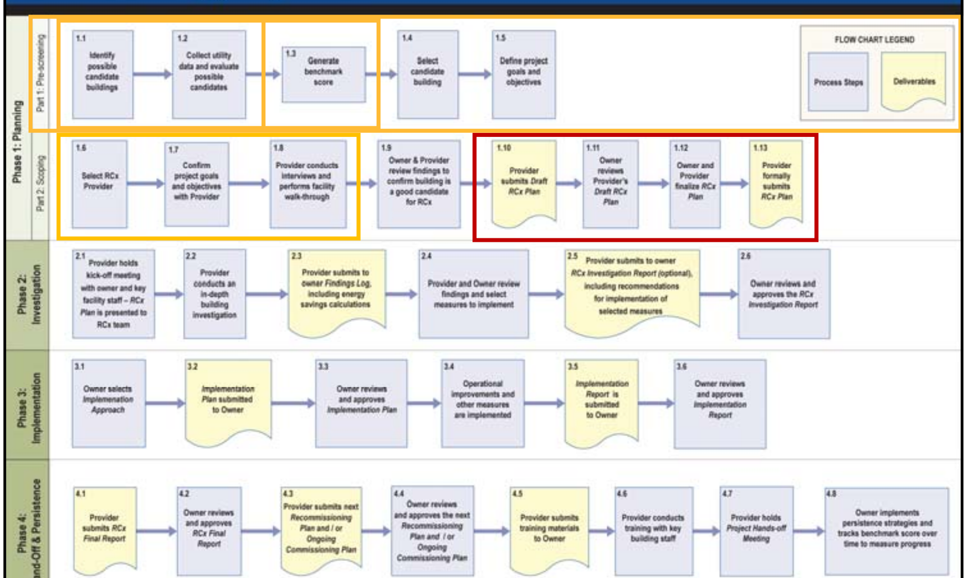
Advanced RCx Course

- Accuracy and repeatability
- Package size and weight
- Cost
- Real time display capability
- Clock accuracy
- Data format
- Memory
- Battery Life
- Speed/sampling rate
- Starting modes
- Input sensor compatibility
- Ease of set up and deployment
- Ease of data retrieval and software compatibility
- Ruggedness and robustness



www.peci.org

Recommissioning (RCx) Process



 www.canmetenergy.nrcan.gc.ca

Recommissioning (RCx) Plan

Advanced RCx Course

- Identify what systems will be investigated to meet owner's project requirements
- Develop a trending/testing plan
  - Sequence of operations verified
  - Points to trend
  - Trend collection frequency
- Coordinate testing times with facility staff
  - Tests to be performed during regular hours
  - Test to be performed after hours

SEE SAMPLE RECOMMISSIONING (RCX) PLAN:
www.canmetenergy.nrcan.gc.ca/recommissioning_plan.html

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Activity: Develop a RCx Plan

Advanced RCx Course

- Develop an RCx plan for example building
  - Separate into small groups
  - Describe what systems will be checked and why
  - Develop a trending/testing plan
    - ➢ Points to trend
    - ➢ Trend collection frequency
    - ➢ Tests to be performed to verify sequence of operations
- Discuss each group's plan as a class

SEE ACTIVITY SHEETS:
- Develop a RCx Plan Form (1 sheet)
- Record Drawings as Reported (5 sheets)
- Sequence of Operations – Heating Water System (5 sheets)
- As-Built Drawings NA01 to NA05 (5 sheets)

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Planning Phase Module

Advanced RCx Course

- What was learned?
  - What buildings make good RCx candidates
  - How to benchmark and scope a building
  - How to develop a comprehensive RCx plan

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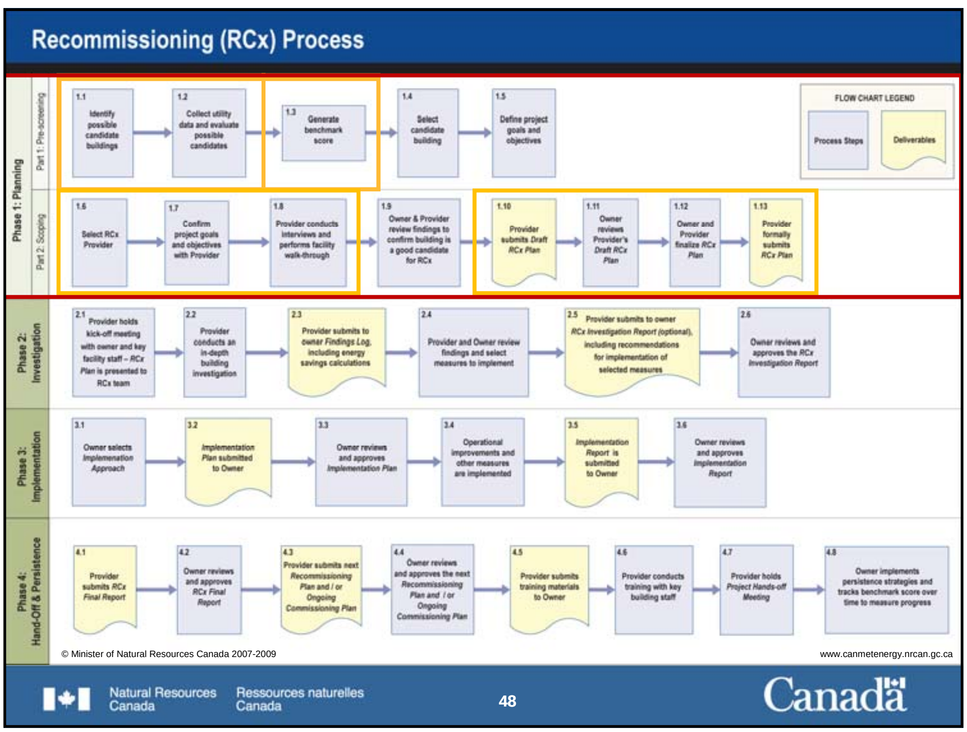

Building Operation Optimization

Advanced Recommissioning (RCx) Course

Phase 2: Investigation

Developed by Portland Energy Conservation, Inc.

P | E | C | I

Adapted by Natural Resources Canada's CanmetENERGY
www.canmetenergy.nrcan.gc.ca

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Phase 2: Investigation

Advanced RCx Course

- Engineering Fundamentals
- In-depth Building Investigation
  - System diagrams
  - System head losses
  - Pumping opportunities
- List of Findings
  - Common RCx measures for schedule, setpoints, resets, economizers, and ventilation control
- RCx Investigation Report (optional)

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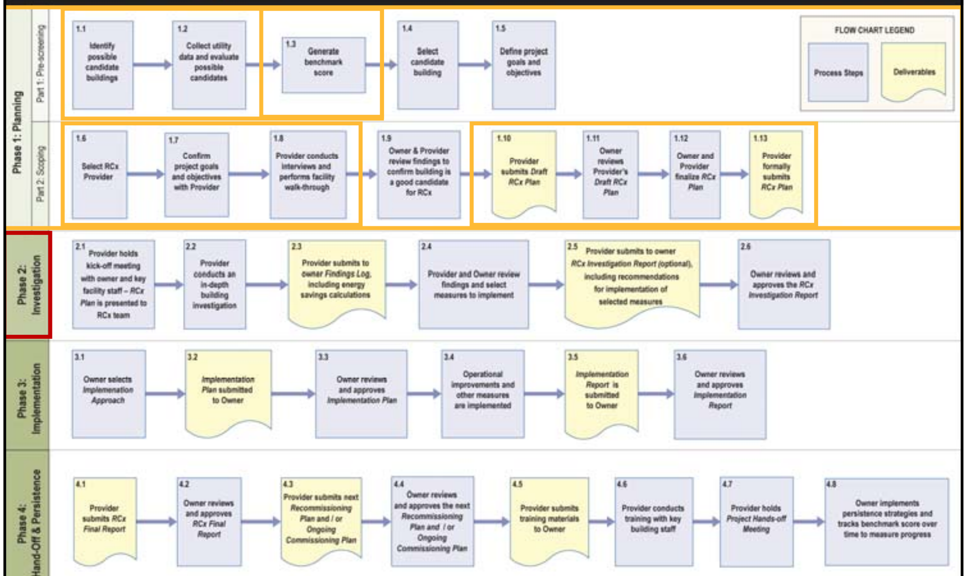
Recommissioning (RCx) Process



 www.canmetenergy.nrcan.gc.ca

Engineering Fundamentals

Advanced RCx Course

- Tools to help us identify savings opportunities
- Calculate savings potential
  - Demand and energy
  - Cost savings
- International Performance Measurement and Verification Protocol (IPMVP)
  - Provides a methodology to validate savings
  - Available via the Efficiency Valuation Organization (EVO)

  www.canmetenergy.nrcan.gc.ca/recommissioning_ipmvp.html

Water Side Load

Advanced RCx Course

Load = Cf x Flow x ΔT

Where:

Load is in Btu/hr (Imperial) or Watts (SI)

Cf = Conversion factor = 500 (Imperial) or 420 (SI)

Flow = Fluid flow rate in USgpm (Imperial) or L/s (SI)

ΔT = Temperature differential across the element in ºF (Imperial) or ºC (SI)

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Sensible Heating or Cooling Loads

Advanced RCx Course

Load = Cf x Flow x ΔT

Where:

Load is in Btu/hr (Imperial) or Watts (SI)

Cf = Conversion factor = 1.08 (Imperial) or 1.2 (SI)

Flow = Air flow rate in cfm (Imperial) or L/s (SI)

ΔT = Temperature differential across the element in ºF (Imperial) or ºC (SI)

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Latent Load

Advanced RCx Course

Load = Cf x Flow x ΔW

Where:

Load is in Btu/hr (Imperial) or Watts (SI)

Cf = Conversion factor = 0.68 (Imperial) or 3.0 (SI)

Flow = Air flow rate in cfm (Imperial) or L/s (SI)

ΔW = Specific humidity change in grains/lb dry air (Imperial) or gram/kg dry air (SI) *(there are 7,000 grains per pound of moisture)*

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Total Load

Advanced RCx Course

Load = Cf x Flow x Δh

Where:

Load is in Btu/hr (Imperial) or Watts (SI)

Cf = Conversion factor = 4.5 (Imperial) or 1.2 (SI)

Flow = Air flow rate in cfm (Imperial) or L/s (SI)

Δh = Enthalpy differential across the element in Btu/lb (Imperial) or kJ/kg (SI)

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The Relationship Between Flow and Velocity

Advanced RCx Course

Flow = Velocity x Area x Cf

Where:

Flow is the air flow rate in cfm (Imperial) or L/s (SI)

Velocity = Air velocity in ft/m (Imperial) or m/s (SI)

Area = Duct cross sectional area in ft^2 (Imperial) or m^2 (SI)

Cf = Conversion factor = 1000 L/m^3 (SI only)

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The Relationship Between Velocity and Velocity Pressure

Advanced RCx Course

Velocity = Cf x $[VP]^{1/2}$

Where:

Velocity = Air flow rate in fpm (Imperial) or m/s (SI)

Cf = Conversion factor = 4005 (Imperial) or 1.27 (SI) *(at standard temperature and pressure - STP)*

VP = Velocity pressure in inches w.c. (Imperial) or Pa (SI)

STP reference conditions for air:

60ºF and 14.7 psi absolute (Imperial)

15ºC and 101.3 kPa absolute (SI)

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Pump Energy

Advanced RCx Course

$Bp = [Flow \times Head \times \rho] / [Cf \times \eta_{pump}]$

Where:

Bp = Brake power into the pump drive shaft in HP (Imperial) or kW (SI)

Flow = Fluid flow rate in USgpm (Imperial) or L/s (SI)

Head = Total pump head in feet w.c. (Imperial) or kPa (SI)

ρ = Fluid density ratio compared to pure water

Cf = Conversion factor = 3960 (Imperial) or 101 (SI)

η_{pump} = Pump efficiency = 40% to 65% for small pumps
75% to 85% for large pumps

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Fan Energy

Advanced RCx Course

$Bp = [Flow \times Head \times \rho] / [Cf \times \eta_{fan}]$

Where:

Bp = Brake power into the fan drive shaft in HP (Imperial) or kW (SI)

Flow = Air flow rate in cfm (Imperial) or L/s (SI)

Head = Total fan static in inches w.c. (Imperial) or kPa (SI)

ρ = Density ratio compared to air at STP

Cf = Conversion factor = 6356 (Imperial) or 40350 (SI)

η_{fan} = Fan efficiency = 40% to 60% for small fans
68% to 78% for large fans

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Useful Conversions

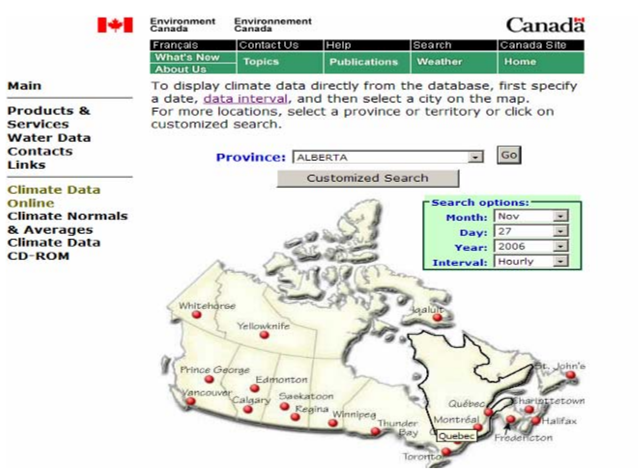
Advanced RCx Course

- 1 cfm = 2.12 L/s
- 200 ft/min ≈ 1 m/s
- 15.85 USgpm = 1 L/s
- 1 US gallon = 3.78 L
- 1 Imp gallon = 4.56 L

SEE UNIT CONVERSION TABLES

Local Climatic Data

Advanced RCx Course



www.canmetenergy.nrcan.gc.ca/rcx_climatic_data_canada.html

Local Climatic Data (con't)

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To display climate data directly from the database, first specify a date, data interval and select a location on the map. For locations not available on the map, click on customized search.

Province: QUEBEC Go

City: MONTREAL Go

Customized Search

Highways

Search options:
Month: Nov
Day: 27
Year: 2006
Interval: Hourly

Local Climatic Data (con't)

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Climate Normals & Averages
Climate Data CD-ROM

MONTREAL/PIERRE ELLIOTT TRUDEAU INTL A QUEBEC

Latitude: 45° 28' N Longitude: 73° 45' W Elevation: 35.70 m
Climate ID: 7025250 WMO ID: 71627 TC ID: YUL

Previous Day | November 15 2006 Go | Next Day

Hourly Data Report for November 15, 2006

Time	Temp °C	Dew Point Temp °C	Rel Hum %	Wind Dir 10's deg	Wind Spd km/h	Visibility km	Stn Press kPa	Hmdx	Wind Chill	Weather
00:00	8.1	7.9	99	22	13	9.7	100.64			Fog
01:00	8.0	8.0	100	22	11	4.0	100.70			Fog
02:00	8.3	8.2	99	22	13	8.0	100.77			Rain, Fog
03:00	8.1	8.0	99	22	11	12.9	100.78			Drizzle
04:00	8.2	7.7	97	22	11	16.1	100.80			Cloudy
05:00	8.0	7.8	99	22	11	9.7	100.85			Drizzle, Fog
06:00	8.3	7.6	95	25	13	12.9	100.90			Cloudy
07:00	8.0	7.6	97	23	11	9.7	100.94			Fog
08:00	8.2	7.1	93	22	11	12.9	100.98			Cloudy
09:00	8.0	7.4	96	22	15	8.0	101.03			Drizzle, Fog
10:00	8.2	7.4	95	23	15	6.4	101.07			Drizzle, Fog
11:00	9.3	7.4	88	26	13	12.9	101.08			Cloudy
12:00	9.2	6.7	84	26	19	16.1	101.09			Cloudy
13:00	9.3	6.7	84	23	19	19.3	101.17			Cloudy
14:00	9.7	6.4	80	27	7	16.1	101.14			Cloudy
15:00	9.5	6.3	80	25	6	24.1	101.14			Cloudy
16:00	9.1	6.3	83	19	7	24.1	101.20			Cloudy
17:00	8.1	6.2	88		0	16.1	101.23			Cloudy
18:00	8.7	6.4	85	22	4	16.1	101.28			Cloudy
19:00	8.4	6.3	87		0	19.3	101.23			Cloudy

Local Climatic Data (con't)

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Climate Data CD-ROM

MONTREAL/PIERRE ELLIOTT TRUDEAU INTL QUEBEC

Latitude: 45° 28' N Longitude: 73° 44' W Elevation: 32.10 m
Climate ID: 702S006 WMO ID: 71183 TC ID: WTQ

Previous Month November 2006 Go

Daily Data Report for November 2006

Day	Max Temp °C	Min Temp °C	Mean Temp °C	Heat Deg Days C	Cool Deg Days C	Total Rain mm	Total Snow cm	Total Precip mm	Snow on Grnd cm	Dir of Max Gust 10's Deg	Spd of Max Gust km/h
01†	9.0	2.7	5.9	12.1	0.0	M	M	0.0		25	33
02†	6.0	0.2	3.1	14.9	0.0	M	M	0.0		28	35
03†	5.3	-2.7	1.3	16.7	0.0	M	M	0.0		27	41
04†	4.8	-4.6	0.1	17.9	0.0	M	M	0.0		27	32
05†	4.9	-0.6	2.2	15.8	0.0	M	M	0.0			<31
06†	9.2	0.7	5.0	13.0	0.0	M	M	0.0			<31
07†	11.4	0.1	5.8	12.2	0.0	M	M	0.0			<31
08†	9.6	5.9	7.8	10.2	0.0	M	M	9.8			<31
09†	12.6	6.0	9.3	8.7	0.0	M	M	3.9		26	41
10†	10.4	3.1	6.8	11.2	0.0	M	M	0.0		30	41
11†	5.8	2.2	4.0	14.0	0.0	M	M	15.8		4	54
12†	4.5	2.2	3.4	14.6	0.0	M	M	2.4		3	44
13†	7.8	4.4	6.1	11.9	0.0	M	M	2.3		3	37
14†	8.9	6.6	7.8	10.2	0.0	M	M	4.1		4	33
15†	9.9	7.0	8.5	9.5	0.0	M	M	1.0			<31
16†	17.3	8.5	12.9	5.1	0.0	M	M	5.6		17	52
17†	16.9	2.3	9.6	8.4	0.0	M	M	1.0		23	56
18†	4.4	1.3	2.9	15.1	0.0	M	M	0.0			<31
19†	2.5	-0.1	1.2	16.8	0.0	M	M	0.0		1	39
20†	1.1	-1.0	0.1	17.9	0.0	M	M	0.0			<31
21†	2.5	-1.9	0.3	17.7	0.0	M	M	0.0			<31
22†	6.5	-2.3	2.1	15.9	0.0	M	M	0.0			<31

Local Climatic Data (con't)

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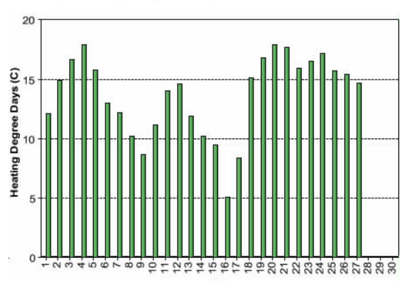
MONTREAL/PIERRE ELLIOTT TRUDEAU INTL QUEBEC

Latitude: 45° 28' N Longitude: 73° 44' W Elevation: 32.10 m
Climate ID: 702S006 WMO ID: 71183 TC ID: WTQ

Previous Month November 2006 Go

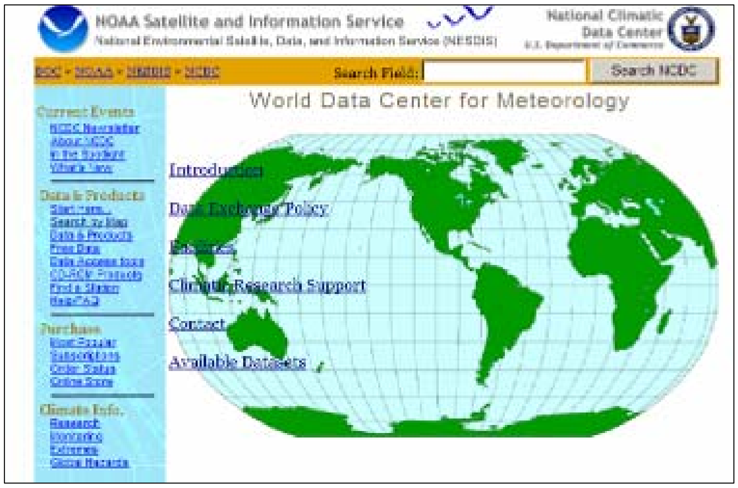
Daily Heating Degree Days for November 2006



Previous Month November 2006 Go

Additional Weather Data Sites

Advanced RCx Course



www.canmetenergy.nrcan.gc.ca/rcx_climatic_data_noaa.html

Another Option: Bin Weather Data

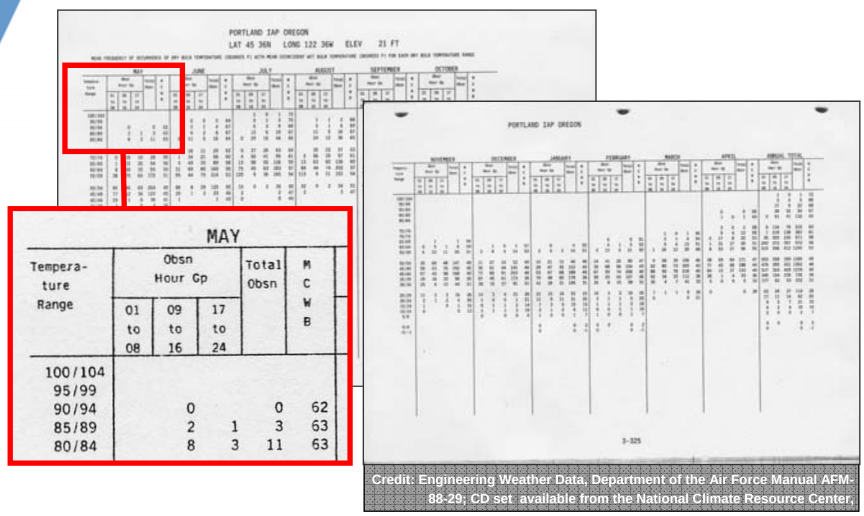
Temp	J		F		M		A		M		J												
	O	I	O	I	O	I	O	I	O	I	O	I	O										
35	0	0	0	0	0	0	0	0	0	0	4	2	5										
32.2	0	0	0	0	0	0	0	0	1	0	2	4	11										
29.4	0	0	0	0	0	0	0	0	6	2	2	15	19										
26.6	0	0	0	0	0	0	0	0	7	4	8	31	25										
23.8	0	0	0	0	0	0	2	4	10	15	43	43	48										
21	0	0	0	0	0	0	3	15	14	32	49	83	30										
18.2	0	0	0	0	0	0	7	29	21	44	33	108	30										
15.4	0	0	0	0	1	0	13	13	47	76	18	101	19										
12.6	0	0	0	0	7	1	22	11	49	73	4	58	9										
9.8	0	3	3	0	7	3	22	42	15	93	9	34	2										
7	0	6	3	0	22	12	45	64	16	93	3	28	0										
4.2	1	9	3	4	38	26	40	74	14	63	6	9	0										
1.4	12	14	18	20	28	82	12	113	5	21	3	11	0										
-1.4	25	29	23	32	31	103	15	65	1	7	4	4	0										
-4.2	31	50	29	88	26	95	4	51	1	8	1	0	0										
-7	31	72	31	60	25	81	3	27	0	3	0	0	0	0	0	0	0	7	0	0	13	42	40	52
-9.8	37	92	28	72	6	71	1	9	0	3	0	0	0	0	0	0	0	7	0	0	11	12	22	71
-12.6	31	88	17	69	3	49	0	10	0	0	0	0	0	0	0	0	0	1	0	0	0	7	24	79
-15.4	21	64	8	70	1	15	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	23	70
-18.2	10	31	7	32	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	34
-21	5	28	3	12	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
-23.8	2	27	3	13	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
-26.6	1	12	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
-29.4	0	10	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-32.2	0	2	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Occupation	
Beginning, day	1 (1 = Monday)
End, day	5 (5 = Friday)
Beginning, hour	9:00
End, hour	17:00
Temperature	
Temperature differential required (ºC)	2.8º
Max (ºC)	35º
Min (ºC)	-32.2º
O = occupied, U = unoccupied	

Metric Units

Another Option: Bin Weather Data

Advanced RCx Course



PORTLAND IAP OREGON

MAY

Temperature Range	Obsn Hour Gp 01 to 08	Obsn Hour Gp 09 to 16	Obsn Hour Gp 17 to 24	Total Obsn	MCWB
100/104					
95/99					
90/94		0		0	62
85/89		2	1	3	63
80/84		8	3	11	63

Credit: Engineering Weather Data, Department of the Air Force Manual AFM-88-29; CD set available from the National Climate Resource Center.

Why Worry About Hourly Data?

Advanced RCx Course

- Part load efficiency can be more significant than design efficiency
  - A 99% cooling design condition means that 1% of the hours will be at or above design …
  - … and 99% of the hours will be at conditions other than design!
  - Compare observed system operation against weather data to help identify problems
- Calculate energy savings

Building Operation Optimization

Advanced Recommissioning (RCx) Course

Phase 2: Investigation
(In-depth Building Investigation)

Developed by Portland Energy Conservation, Inc.

P | E | C | I

Adapted by Natural Resources Canada's CanmetENERGY

www.canmetenergy.nrcan.gc.ca

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Phase 2: Investigation (In-depth Building Investigation)

Advanced RCx Course

- System diagrams
- System head losses
- Pumping opportunities

ACTIVITIES:

- Review system diagram and pump test analysis
- Perform a comprehensive pumping system analysis
- Evaluate savings associated with a pumping system

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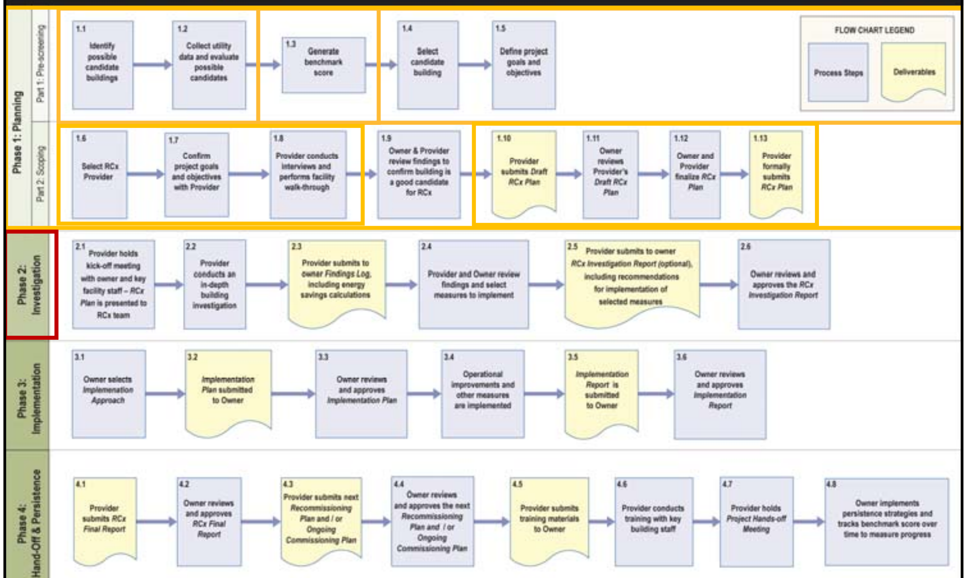
Recommissioning (RCx) Process



 www.canmetenergy.nrcan.gc.ca

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Assessing System Configuration

Advanced RCx Course

- System configuration fundamental to system analysis
- System diagrams
  - Firm foundation for next steps
  - Provide a real world understanding of the systems
  - Provide exposure to other indicators
  - RCx persistence enabler
- Developing a system diagram can make the hidden obvious!

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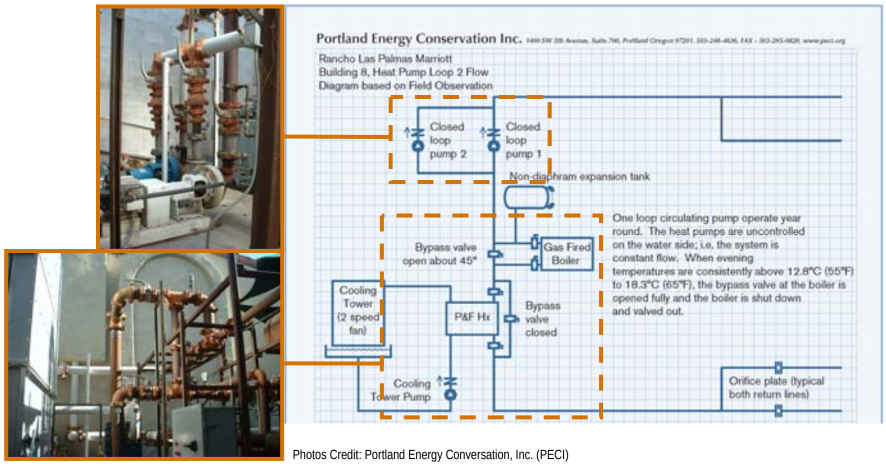
What Appears Physically Complex…

Advanced RCx Course

… many be schematically simple



Photos Credit: Portland Energy Conversation, Inc. (PECI)

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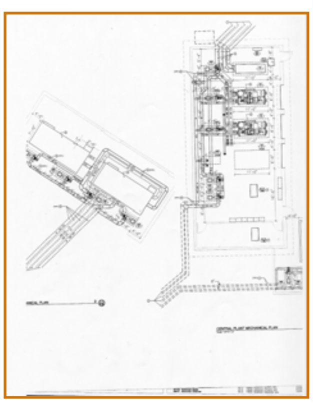
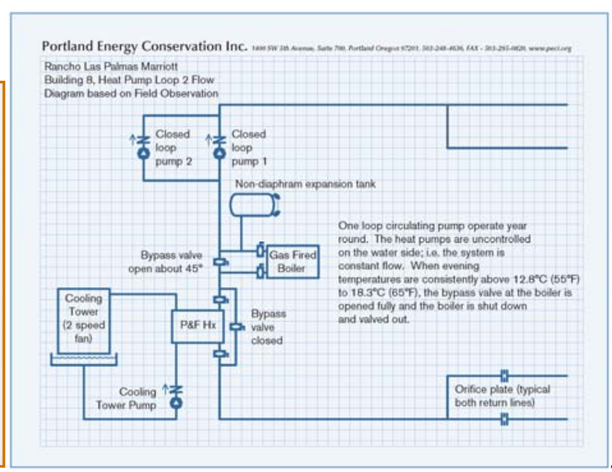
Floor Plans
A Practical Presentation Format for Fabrication

Advanced RCx Course

Schematics: a crucial presentation format for understanding operation





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Making a System Diagram…

… will cause you to see the system from a different perspective

Initial Impression:
A decoupled secondary circuit

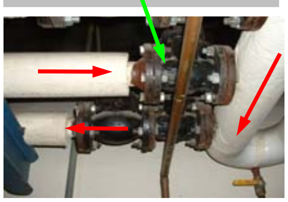
Photos Credit:
Portland Energy Conversation, Inc. (PECI)

Making a System Diagram…

Advanced RCx Course

… will cause you to see the system from a different perspective

Check valve



Red arrows show flow direction

Upon closer inspection:
The secondary supply and return connections are reversed

Check valve viewed from the side opposite the direction of view in the other picture

Photos Credit: Portland Energy Conversation, Inc. (PECI)

Key Points

Advanced RCx Course

- Include all interactive components
- “Untangled”
- Generally diagrammatic
- Illustrate all elements that can affect flow rate or path
- Pay attention to the order of connection

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Tangled vs. Untangled

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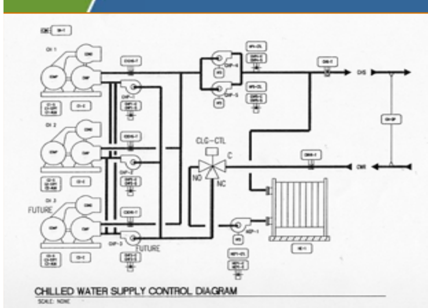
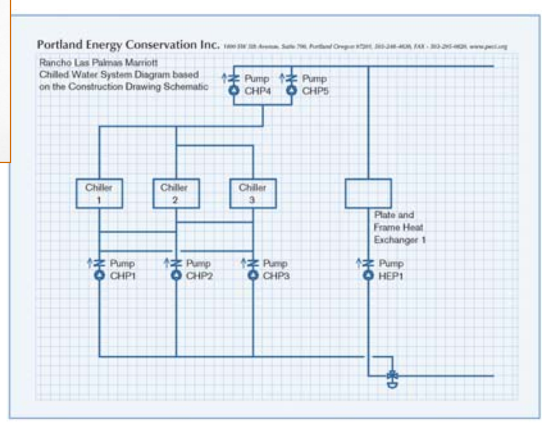


- Minimize line crossings
- Elbows don’t matter
- Looks like a ladder on its side



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Order of Connection can Matter
As Drawn from the Contract Documents…

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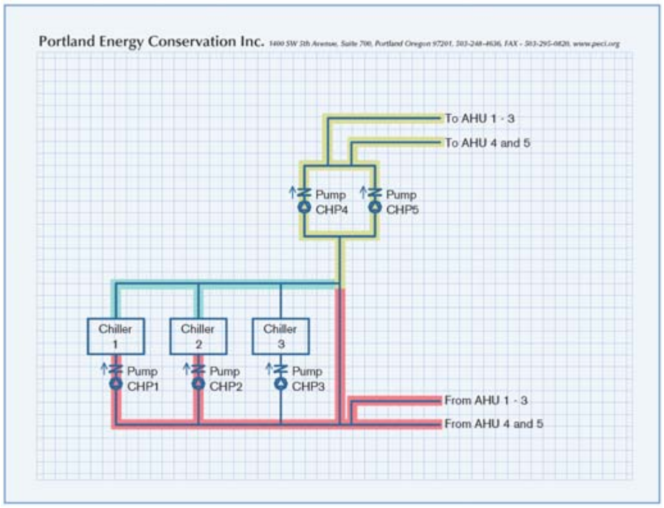
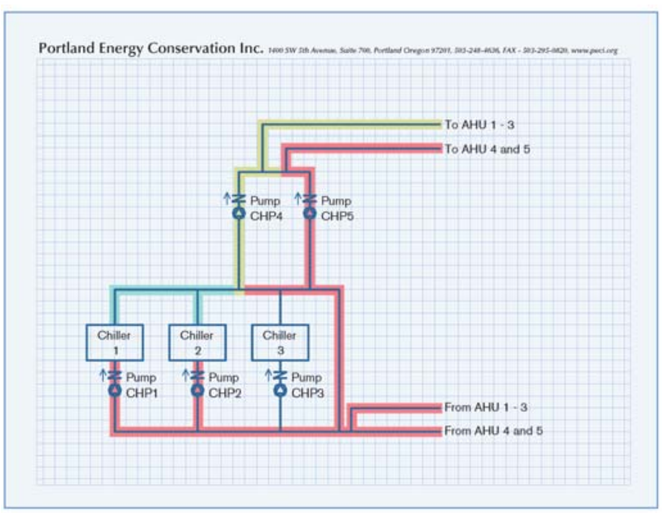


… all loads receive the same supply water temperature

As Drawn Based on the "As Piped" Field Conditions

Advanced RCx Course

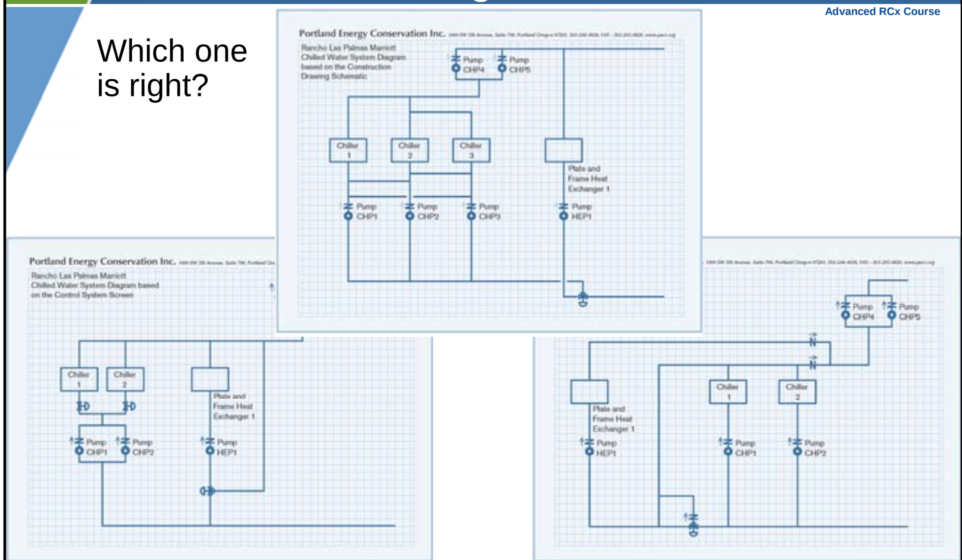


… some loads could receive warmer water if there is bypass flow from the return

Same Project, Same System, Three Different Diagrams

Advanced RCx Course

Which one is right?



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None of Them!

And the differences are the explanations for operational problems

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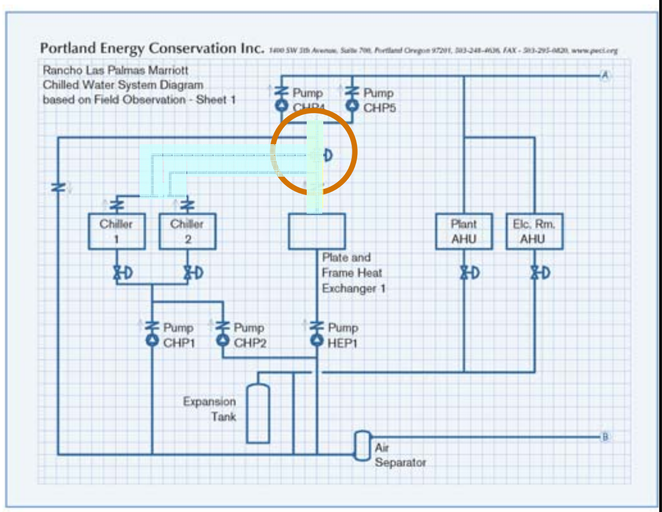
The three-way valve does nothing (except knock the plant off-line if it trips)



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None of Them!

And the differences are the explanations for operational problems

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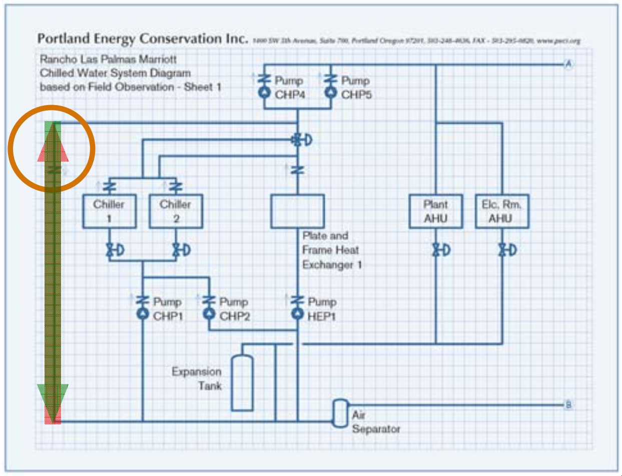
An un-recognized check valve eliminates decoupling under some conditions



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Using a Pipe Friction Chart

Advanced RCx Course

- The friction rate for a 100 mm line carrying 12.6 L/s is a little over 200 Pa per linear meter of pipe
- The velocity in the pipe is about 1.5 m/s

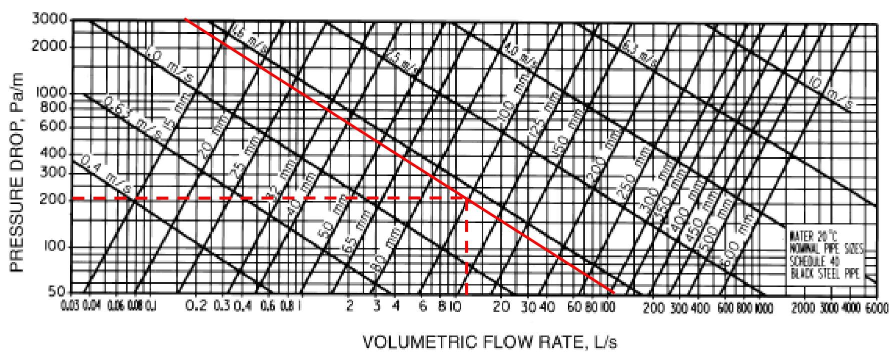

Fig. 1 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

Source: ASHRAE Fundamentals 1997, section 33.5.

Metric Units

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Using a Pipe Friction Chart

Advanced RCx Course

- The friction rate for a 4” line carrying 200 gpm is about 2.25 ft.w.c. per 100 linear feet of pipe
- The velocity in the pipe is about 5 feet per second

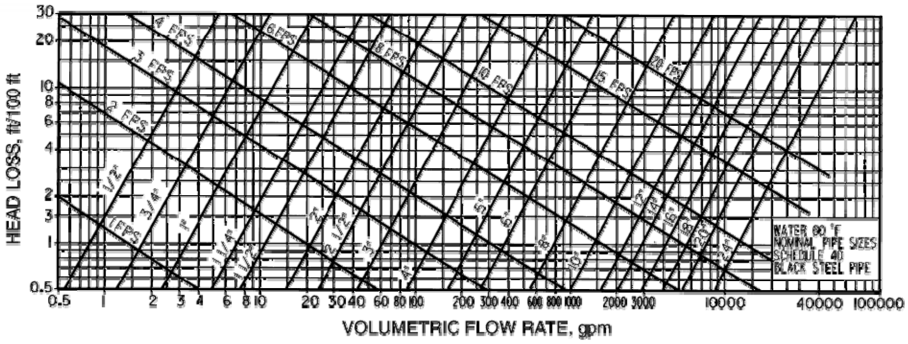


Fig. 1 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

Source: ASHRAE Fundamentals 1997, section 33.5.

Same Example Using a Chart

- The friction rate for a 4” line carrying 200 gpm is about 2.25 ft.w.c. per 100 linear feet of pipe
- The velocity in the pipe is about 5 feet per second

INGERSOLL-RAND CAMERON HYDRAULIC DATA

Friction of Water **Asphalt-dipped Cast Iron and New Steel Pipe**
(Based on Darcy's Formula)
4 Inch
(Continued)

Flow U S gal per min	Asphalt-dipped cast iron, 4.0" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Std wt steel sch 40, 4.026" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Extra strong steel sch 80, 3.826" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Schedule 160—steel, 3.438" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft
20	.511	.004	.038	.504	.004	.035	.56	.00	.045	.691	.007	.074
30	.766	.009	.076	.756	.009	.072	.84	.01	.092	1.04	.017	.154
40	1.02	.016	.128	1.01	.016	.120	1.12	.02	.153	1.38	.030	.258
50	1.28	.025	.194	1.26	.025	.179	1.40	.03	.230	1.73	.046	.387
60	1.53	.037	.273	1.51	.036	.250	1.67	.04	.320	2.07	.067	.540
70	1.79	.050	.365	1.76	.048	.330	1.95	.06	.424	2.42	.091	.691
80	2.04	.065	.470	2.02	.063	.422	2.23	.08	.541	2.77	.119	.885
90	2.30	.082	.588	2.27	.080	.523	2.51	.10	.649	3.11	.150	1.10
100	2.55	.101	.719	2.52	.099	.613	2.79	.12	.789	3.46	.185	1.34
110	2.81	.123	.862	2.77	.119	.732	3.07	.15	.943	3.80	.224	1.61
120	3.06	.146	1.02	3.02	.142	.861	3.35	.17	1.11	4.15	.267	1.89
130	3.32	.171	1.19	3.28	.167	1.00	3.63	.20	1.29	4.49	.313	2.20
140	3.57	.199	1.37	3.53	.193	1.15	3.91	.24	1.48	4.84	.363	2.53
150	3.83	.228	1.57	3.78	.222	1.31	4.19	.27	1.69	5.18	.417	2.89
160	4.08	.259	1.77	4.03	.253	1.48	4.47	.31	1.91	5.53	.475	3.26
170	4.34	.293	1.99	4.28	.285	1.66	4.75	.35	2.14	5.88	.536	3.66
180	4.60	.328	2.23	4.54	.320	1.85	5.02	.39	2.38	6.22	.601	4.09
190	4.85	.368	2.47	4.79	.356	2.05	5.30	.44	2.64	6.57	.669	4.53
200	5.11	.406	2.73	5.04	.395	2.25	5.58	.48	2.91	6.91	.742	5.00
220	5.62	.490	3.29	5.54	.478	2.70	6.14	.59	3.49	7.60	.897	6.00
240	6.13	.583	3.90	6.05	.569	3.19	6.70	.70	4.13	8.30	1.07	7.09
260	6.64	.685	4.55	6.55	.667	3.72	7.26	.82	4.81	8.99	1.25	8.27
280	7.15	.794	5.26	7.06	.774	4.28	7.82	.95	5.54	9.68	1.45	9.55
300	7.66	.912	6.02	7.56	.888	4.89	8.38	1.09	6.33	10.37	1.67	10.9
320	8.17	1.04	6.84	8.06	1.01	5.53	8.94	1.24	7.17	11.06	1.90	12.4
340	8.68	1.17	7.70	8.57	1.14	6.22	9.50	1.40	8.06	11.75	2.14	13.9
360	9.19	1.31	8.61	9.07	1.28	6.94	10.0	1.6	9.00	12.44	2.40	15.5
380	9.70	1.46	9.58	9.58	1.43	7.71	10.6	1.7	9.99	13.13	2.68	17.3
400	10.2	1.62	10.6	10.1	1.58	8.51	11.2	1.9	11.0	13.82	2.97	19.1
420	10.7	1.79	11.6	10.6	1.74	9.35	11.7	2.1	12.1	14.52	3.27	21.0
440	11.2	1.96	12.8	11.1	1.91	10.2	12.3	2.3	13.3	15.21	3.59	22.9
460	11.7	2.14	13.9	11.6	2.09	11.2	12.8	2.5	14.5	15.90	3.92	25.0
480	12.3	2.33	15.2	12.1	2.27	12.1	13.4	2.8	15.7	16.59	4.27	27.2
500	12.8	2.53	16.4	12.6	2.47	13.1	14.0	3.0	17.0	17.28	4.64	29.5
550	14.0	3.06	19.8	13.9	2.99	15.8	15.3	3.6	20.5	19.00	5.61	35.5
600	15.3	3.65	23.6	15.1	3.55	18.7	16.7	4.3	24.3	20.74	6.67	42.1
650	16.6	4.28	27.6	16.4	4.17	21.7	18.1	5.1	28.4	22.46	7.83	49.2
700	17.9	4.96	32.0	17.6	4.84	25.3	19.5	5.9	32.8	24.19	9.08	57.0
750	19.1	5.70	36.6	18.9	5.55	28.9	20.9	6.8	37.6	25.92	10.4	65.2
800	20.4	6.48	41.6	20.2	6.32	32.8	22.3	7.7	42.7	27.65	11.7	74.1
850	21.7	7.32	46.9	21.4	7.13	37.0	23.7	8.7	48.1	29.38	13.4	83.4
900	23.0	8.20	52.6	22.7	8.00	41.4	25.1	9.8	53.8	31.10	15.0	93.4
950	24.3	9.14	58.5	[illegible]	8.91	46.0	26.5	10.9	59.8	32.83	16.7	104
1000	25.5	10.1	64.8	25.2	9.87	50.9	27.9	12.1	66.2	34.56	18.5	115
1100	28.1	12.3	78.3	27.7	11.9	61.4	30.7	14.6	79.8	38.02	22.4	139

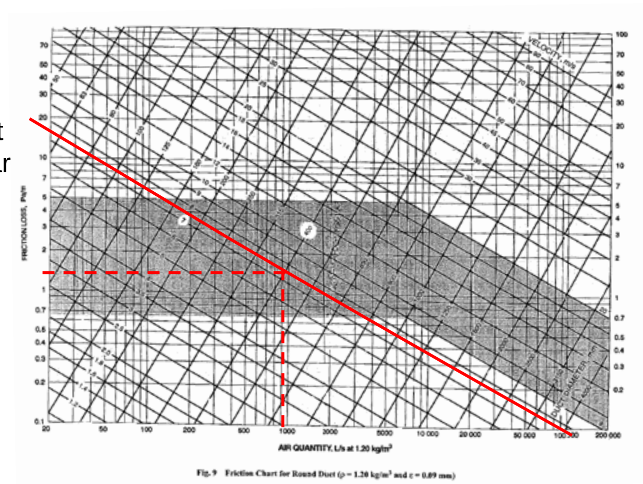
Note: No allowance has been made for age, difference in diameter, or any abnormal condition of interior surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation. It is recommended that for most commercial design purposes a safety factor of 15 to 20% be added to the values in the tables—see page 3-5.

Source: Cameron Hydraulic Data

Using an Air Friction Chart

Advanced RCx Course

- The loss for a 400 mm round duct carrying 944 L/s is about 1.4 Pa per linear meter of duct
- The velocity is a little over 7 m/s



Source: ASHRAE Fundamentals 1997, section 32.9.

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Metric Units

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Using an Air Friction Chart

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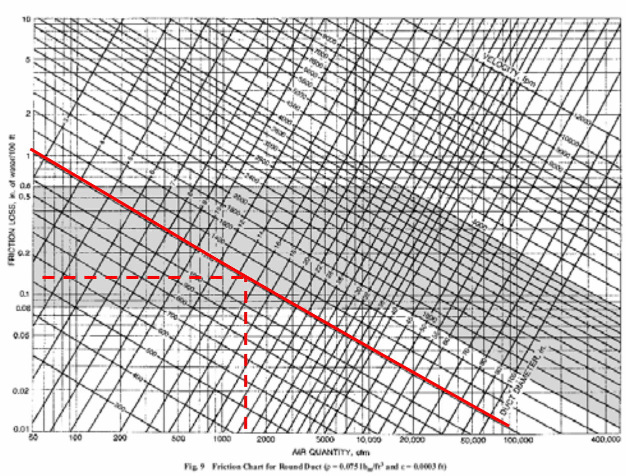
- The loss for a 16" round duct carrying 2,000 cfm is about 0.18 in. w.c. per 100 linear feet of duct
- The velocity is a little over 1,400 ft per minute



Source: ASHRAE Fundamentals 1997, section 32.9.

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Imperial Units

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Round Duct Equivalents

Advanced RCx Course

- A 300 mm round duct is equivalent to a 125 mm x 700 mm duct
- or a 250 mm x 300 mm duct (and a number of things in between)

Table 2 Circular Equivalents of Rectangular Duct for Equal Friction and Capacity[a]

Lgth Adj.[b]	Length One Side of Rectangular Duct (a), mm: 100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750
	Circular Duct Diameter, mm																	
100	109																	
125	122	137																
150	133	150	164															
175	143	161	177	191														
200	152	172	189	204	219													
225	161	181	200	216	232	246												
250	169	190	210	228	244	259	273											
275	176	199	220	238	256	272	287	301										
300	183	207	229	248	266	283	299	314	328									
350	195	222	245	267	286	305	322	339	354	383								
400	207	235	260	283	305	325	343	361	378	409	437							
450	217	247	274	299	321	343	363	382	400	433	464	492						
500	227	258	287	313	337	360	381	401	420	455	488	518	547					
550	236	269	299	326	352	375	398	419	439	477	511	543	573	601				
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656			
650	253	289	321	351	378	404	429	452	474	515	553	589	622	653	683	711		
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765	
750	268	306	341	373	402	430	457	482	506	550	592	630	666	700	732	763	792	820

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Metric Units

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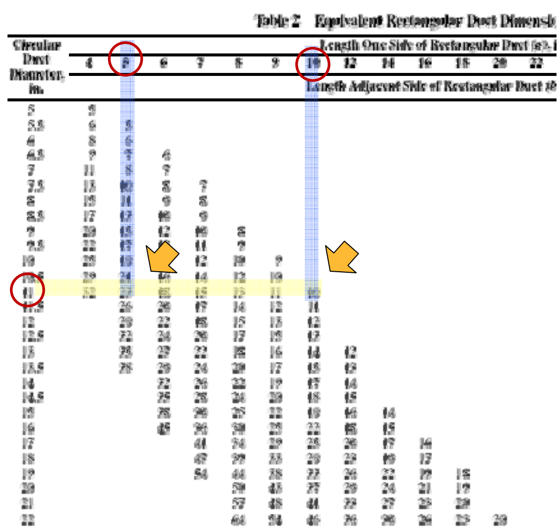
Round Duct Equivalents

Advanced RCx Course

- A 12” round duct is equivalent to a 5” x 29” duct
- or a10” x 12” duct (and a number of things in between)



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Imperial Units

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Fitting Pressure Losses

Advanced RCx Course

- Equivalent length of new pipe for various fitting types, connection design, and material.
- These charts assume all valves are in the wide-open position

Equivalent Length of Straight Pipe for Valves and Fittings (meter)

Flanged Fittings		Pipe Size												
		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	8	10
Elbows	Regular 90 deg	0.3	0.4	0.5	0.6	0.7	0.9	1.1	1.3	1.8	2.2	2.7	3.7	4.3
	Long radius 90 deg	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.3	1.5	1.7	2.1	2.4
	Regular 45 deg	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.1	1.4	1.7	2.3	2.7
Tees	Line flow	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.9	1.0	1.2	1.4	1.6
	Branch flow	0.6	0.8	1.0	1.3	1.6	2.0	2.3	2.9	3.7	4.6	5.5	7.3	9.2
Return Bends	Regular 180 deg	0.3	0.4	0.5	0.6	0.7	0.9	1.1	1.3	1.8	2.2	2.7	3.7	4.3
	Long radius 180 deg	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.3	1.5	1.7	2.1	2.4
Valves	Globe	11.6	12.2	13.7	16.5	18.0	21.4	23.5	28.7	36.6	45.8	58.0	79.3	94.6
	Gate	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0
	Angle	4.6	4.6	5.2	5.5	5.5	6.4	6.7	8.5	11.6	15.3	19.2	27.5	36.6

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Equivalent Length of Straight Pipe for Valves and Fittings (m)

Screwed Fittings		Pipe Size										
		1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
Elbows	Regular 90 deg	0.7	0.9	1.1	1.3	1.6	2.0	2.3	2.6	2.8	3.4	4.0
	Long radius 90 deg	0.5	0.6	0.7	0.7	0.8	1.0	1.0	1.1	1.1	1.2	1.4
	Regular 45 deg	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.7
Tees	Line flow	0.2	0.4	0.5	0.7	1.0	1.4	1.7	2.3	2.8	3.7	5.2
	Branch flow	0.7	1.1	1.3	1.6	2.0	2.7	3.0	3.7	4.0	5.2	6.4
Return Bends	Regular 180 deg	0.7	0.9	1.1	1.3	1.6	2.0	2.3	2.6	2.8	3.4	4.0
Valves	Globe	6.4	6.7	6.7	7.3	8.8	11.3	12.8	16.5	18.9	24.1	33.6
	Gate	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.8
	Angle	3.9	4.6	4.6	4.6	5.2	5.5	5.5	5.5	5.5	5.5	5.5
	Swing Check	2.2	2.2	2.4	2.7	3.4	4.0	4.6	5.8	6.7	8.2	11.6
Strainer			1.4	1.5	2.0	2.3	5.5	6.1	8.2	8.8	10.4	12.8

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Metric Units

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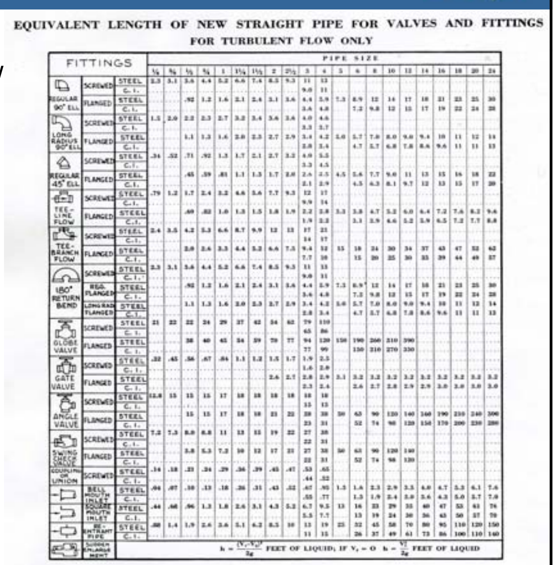
Fitting Pressure Losses

- Equivalent length of new pipe for various fitting types, connection design, and material
- This chart assumes all valves are in the wide-open position



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Imperial Units

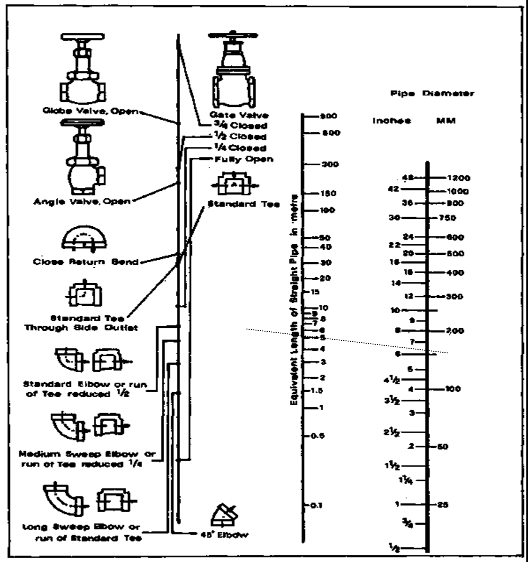
24

Canada

Fitting Losses

- Pressure loss depicted in graphical form
- Assumes schedule 40 steel pipe
- Does not consider connection type
- Provides loss estimate for partially open gate valves

Example: The dotted line shows that the resistance of a 150 mm standard elbow is equivalent to approximately 4.9 m of 150 mm standard pipe.



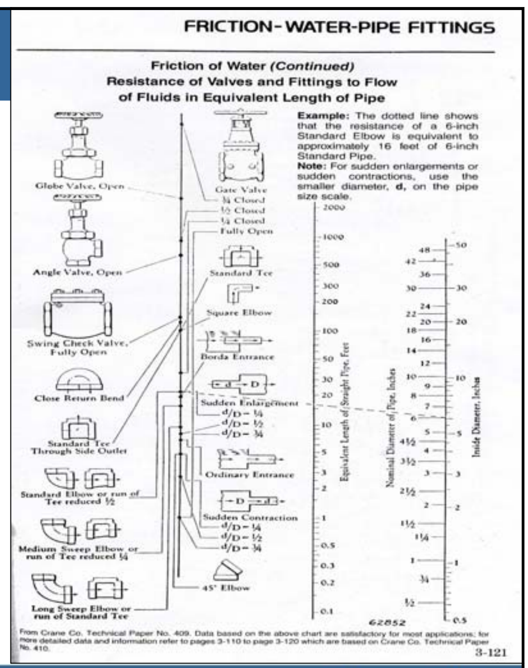
Source: www.fao.org

Natural Resources Canada Ressources naturelles Canada

Metric Units

Canada

Fitting Losses



- Pressure loss depicted in graphical form
- Assumes Schedule 40 steel pipe
- Does not consider connection type
- Provides loss estimate for partially open gate valves

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Imperial Units

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Sample Head Loss Estimates

Component Common to both Pumps	Diameter (mm)	Design flow	Head Loss per meter (meter w.c.)	Actual Length or Equivalent Length in meters	Min Loss (meter w.c.)	Max Loss (20% factor) (meter w.c.)
250 mm sch 40 pipe	250	318	0.00938	9.1	0.09	0.10
250 mm elbows (Qty: 1)	250	450	0.00938	5.5	0.05	0.06
250 mm Tee (Qty: 5)	250	450	0.00938	27.4	0.26	0.31
250 mm to 200 mm Tee (Qty: 2)	250	450	0.0186	11.0	0.20	0.24
Estimated System Head Loss for Common Components					**0.60**	**0.72**
Component for CHWP1	**Diameter (mm)**	**Design flow**	**Head Loss per meter (meter w.c.)**	**Actual Length or Equivalent Length in meters**	**Min Loss (meter w.c.)**	**Max Loss (20% factor) (meter w.c.)**
150 mm sch 40 pipe	150	159	0.0313	11.0	0.34	0.41
150 mm isolation valves (full open – Qty: 3)	150	159	0.0313	4.6	0.14	0.17
150 mm check valve (Qty: 1)	150	159	0.0313	15.2	0.48	0.57
150 mm throttle valves (full open – Qty: 1)	150	159	0.0313	1.5	0.05	0.06
150 mm suction diffuser (Victaulic 731)	150	159	0.02	30.5	0.61	0.73
150 mm elbows (Qty: 6)	150	159	0.0313	32.9	1.03	1.24
150 mm tees (Qty: 3)	150	159	0.0313	16.5	0.52	0.62
Evaporator bundle (mfgr data)					5.79	6.95
System head Loss for CHWP1 Components					8.96	10.75
Estimated Total System Head Loss for CHWP1					**9.56**	**11.47**
Rated Pump Head					**13.7**	

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Metric Units

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Canada

Sample Head Loss Estimates

Component Common to both Pumps	Diameter (inches)	Design flow	Head Loss per meter (feet w.c.)	Actual Length or Equivalent Length in feet	Min Loss (feet w.c.)	Max Loss (20% factor) (feet w.c.)
10" sch 40 pipe	10	1,400	0.938	30	0.3	0.3
10" elbows (Qty: 1)	10	1,400	0.938	18	0.2	0.2
10" Tee (Qty: 5)	10	1,400	0.938	90	0.8	1.0
10" to 8" Tee (Qty: 2)	10	1,400	1.86	36	0.7	0.8
Estimated System Head Loss for Common Components					**2.0**	**2.4**
Component for CHWP1	**Diameter (inches)**	**Design flow**	**Head Loss per meter (feet w.c.)**	**Actual Length or Equivalent Length in feet**	**Min Loss (feet w.c.)**	**Max Loss (20% factor) (feet w.c.)**
6" sch 40 pipe	6	700	3.13	36	1.1	1.4
6" isolation valves (full open – Qty: 3)	6	700	3.13	15	0.5	0.6
6" check valve (Qty: 1)	6	700	3.13	50	1.6	1.9
6" throttle valves (full open – Qty: 1)	6	700	3.13	5	0.2	0.2
6" suction diffuser (Victaulic 731)	6	700	2	100	2.31	2.772
6" elbows (Qty: 6)	6	700	3.13	100	3.4	4.1
6" tees (Qty: 3)	6	700	3.13	54	1.7	2.0
Evaporator bundle (mfgr data)					19	22.8
System head Loss for CHWP1 Components					29.7	35.6
Estimated Total System Head Loss for CHWP1					**31.7**	**38.0**
Rated Pump Head					**45.0 feet**	

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Imperial Units

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Canada

Correction Factors

Advanced RCx Course

- When testing systems consisting of anything other than pure water, use of correction factors for specific gravity and viscosity may be necessary
- Friction loss through piping, fittings, and components increases dramatically as viscosity of the liquid rises
- Viscous liquids tend to increase pump horsepower requirements and reduce rated efficiency, capacity, and head
- All measured pressure readings should be adjusted to take into account the specific gravity (S.G.) of the liquid *(liquid density = water density / S.G)*
  - Ft.HD = [PSI x 2.31 ft/psi] / S.G.
  - kPa = kPa / S.G.

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Pipe Friction Correction

INGERSOLL-RAND CAMERON HYDRAULIC DATA

Friction of Water — **Asphalt-dipped Cast Iron and New Steel Pipe** (Based on Darcy's Formula) **4 Inch** *(Continued)*

Flow U S gal per min	Asphalt-dipped cast iron, 4.0" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Std wt steel sch 40, 4.026" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Extra strong steel sch 80, 3.826" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft	Schedule 160—steel, 3.438" inside dia: Velocity ft per sec	Velocity head ft	Head loss ft per 100 ft
20	.511	.004	.038	.504	.004	.035	.56	.00	.045	.691	.007	.074
30	.766	.009	.076	.756	.009	.072	.84	.01	.092	1.04	.017	.154
40	1.02	.016	.128	1.01	.016	.120	1.12	.02	.153	1.38	.030	.258
50	1.28	.025	.194	1.26	.025	.179	1.40	.03	.230	1.73	.046	.387
60	1.53	.037	.273	1.51	.036	.250	1.67	.04	.320	2.07	.067	.540
70	1.79	.050	.365	1.76	.048	.330	1.95	.06	.424	2.42	.091	.691
80	2.04	.065	.470	2.02	.063	.422	2.23	.08	.541	2.77	.119	.885
90	2.30	.082	.588	2.27	.080	.523	2.51	.10	.649	3.11	.150	1.10
100	2.55	.101	.719	2.52	.099	.613	2.79	.12	.789	3.46	.185	1.34
110	2.81	.123	.862	2.77	.119	.732	3.07	.15	.943	3.80	.224	1.61
120	3.06	.146	1.02	3.02	.142	.861	3.35	.17	1.11	4.15	.267	1.89
130	3.32	.171	1.19	3.28	.167	1.00	3.63	.20	1.29	4.49	.313	2.20
140	3.57	.199	1.37	3.53	.193	1.15	3.91	.24	1.48	4.84	.363	2.53
150	3.83	.228	1.57	3.78	.222	1.31	4.19	.27	1.69	5.18	.417	2.89
160	4.08	.259	1.77	4.03	.253	1.48	4.47	.31	1.91	5.53	.475	3.26
170	4.34	.293	1.99	4.28	.285	1.66	4.75	.35	2.14	5.88	.536	3.66
180	4.60	.328	2.23	4.54	.320	1.85	5.02	.39	2.38	6.22	.601	4.09
190	4.85	.368	2.47	4.79	.356	2.05	5.30	.44	2.64	6.57	.669	4.53
200	5.11	.406	2.73	5.04	.395	2.25	5.58	.48	2.91	6.91	.742	5.00
220	5.62	.490	3.29	5.54	.478	2.70	6.14	.59	3.49	7.60	.897	6.00
240	6.13	.583	3.90	6.05	.569	3.19	6.70	.70	4.13	8.30	1.07	7.09
260	6.64	.685	4.55	6.55	.667	3.72	7.26	.82	4.81	8.99	1.25	8.27
280	7.15	.794	5.26	7.06	.774	4.28	7.82	.95	5.54	9.68	1.45	9.55
300	7.66	.912	6.02	7.56	.888	4.89	8.38	1.09	6.33	10.37	1.67	10.9
320	8.17	1.04	6.84	8.06	1.01	5.53	8.94	1.24	7.17	11.06	1.90	12.4
340	8.68	1.17	7.70	8.57	1.14	6.22	9.50	1.40	8.06	11.75	2.14	13.9
360	9.19	1.31	8.61	9.07	1.28	6.94	10.0	1.6	9.00	12.44	2.40	15.5
380	9.70	1.46	9.58	9.58	1.43	7.71	10.6	1.7	9.99	13.13	2.68	17.3
400	10.2	1.62	10.6	10.1	1.58	8.51	11.2	1.9	11.0	13.82	2.97	19.1
420	10.7	1.79	11.6	10.6	1.74	9.35	11.7	2.1	12.1	14.52	3.27	21.0
440	11.2	1.96	12.8	11.1	1.91	10.2	12.3	2.3	13.3	15.21	3.59	22.9
460	11.7	2.14	13.9	11.6	2.09	11.2	12.8	2.5	14.5	15.90	3.92	25.0
480	12.3	2.33	15.2	12.1	2.27	12.1	13.4	2.8	15.7	16.59	4.27	27.2
500	12.8	2.53	16.4	12.6	2.47	13.1	14.0	3.0	17.0	17.28	4.64	29.5
550	14.0	3.06	19.8	13.9	2.99	15.8	15.3	3.6	20.5	19.00	5.61	35.5
600	15.3	3.65	23.6	15.1	3.55	18.7	16.7	4.3	24.3	20.74	6.67	42.1
650	16.6	4.28	27.6	16.4	4.17	21.7	18.1	5.1	28.4	22.46	7.83	49.2
700	17.9	4.96	32.0	17.6	4.84	25.3	19.5	5.9	32.8	24.19	9.08	57.0
750	19.1	5.70	36.6	18.9	5.55	28.9	20.9	6.8	37.6	25.92	10.4	65.2
800	20.4	6.48	41.6	20.2	6.32	32.8	22.3	7.7	42.7	27.65	11.7	74.1
850	21.7	7.32	46.9	21.4	7.13	37.0	23.7	8.7	48.1	29.38	13.4	83.4
900	23.0	8.20	52.6	22.7	8.00	41.4	25.1	9.8	53.8	31.10	15.0	93.4
950	24.3	9.14	58.5	23.9	8.91	46.0	26.5	10.9	59.8	32.83	16.7	104
1000	25.5	10.1	64.8	25.2	9.87	50.9	27.9	12.1	66.2	34.56	18.5	115
1100	28.1	12.3	78.3	27.7	11.9	61.4	30.7	14.6	79.8	38.02	22.4	139

Note: No allowance has been made for age, difference in diameter, or any abnormal condition of interior surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation. It is recommended that for most commercial design purposes a safety factor of 15 to 20% be added to the values in the tables—see page 3-5.

INGERSOLL-RAND CAMERON HYDRAULIC DATA

Friction Loss for Viscous Liquids *(Continued)*
(Based on Darcy's Formula)
Loss in Feet of Liquid per 1000 Feet of Pipe
4 Inch (4.026" inside dia) Sch 40 New Steel Pipe

Flow U S gal per min	Bbl per hr (42 gal)	Kinematic viscosity—centistokes: .6	1.1	2.1	2.7	4.3	7.4	10.3	13.1	15.7	20.6
	Approx SSU viscosity		31.5	33	35	40	50	60	70	80	100
20	28.6	.30	.34	.40	.43	.49	.57	.50	.63	.75	.99
30	42.9	.62	.70	.82	.87	.98	1.14	1.25	.95	1.13	1.49
40	57.1	1.05	1.18	1.35	1.44	1.62	1.86	2.04	2.20	1.51	1.96
50	71.4	1.58	1.76	2.02	2.13	2.37	2.75	3.00	3.21	3.40	2.47
60	85.7	2.22	2.44	2.80	2.93	3.27	3.77	4.12	3.29	4.62	3.01
70	100	2.96	3.24	3.69	3.88	4.31	4.93	5.39	5.72	6.03	6.53
80	114	3.79	4.16	4.67	4.93	5.44	6.20	6.78	7.23	7.55	8.17
90	129	4.72	5.15	5.77	6.08	6.72	7.63	8.32	8.87	[illegible]	10.0
100	143	5.77	6.27	6.91	7.33	8.12	9.15	9.97	10.8	11.2	12.0
120	171	8.09	8.81	9.66	10.2	11.2	12.7	13.6	14.6	15.3	16.5
140	200	10.8	11.7	12.9	13.4	14.8	16.6	17.9	19.0	20.0	21.6
160	228	13.9	15.0	16.4	17.1	18.8	21.1	22.7	24.0	25.2	27.2
180	257	17.4	18.7	20.4	21.5	23.2	26.0	28.1	29.6	30.8	33.3
200	286	21.4	22.7	24.9	25.9	28.0	31.4	33.7	35.7	36.9	40.0
220	314	25.6	27.2	29.8	30.8	33.2	37.3	40.2	42.3	44.0	47.0
240	343	30.3	32.0	34.9	36.1	38.8	43.4	46.8	49.1	51.4	54.6
260	371	35.4	37.2	40.4	42.0	45.0	50.1	53.9	56.7	59.3	62.7
280	400	40.8	42.7	46.4	48.2	51.7	57.4	61.6	65.0	67.4	71.3
300	429	46.6	48.7	53.0	54.8	58.8	64.9	69.6	73.3	76.0	81.0
350	500	62.7	65.6	70.6	72.8	77.9	85.4	91.2	96.2	101	107
400	571	81.4	84.7	90.4	93.7	99.8	109	116	122	127	135
450	643	102	106	113	117	124	135	144	151	157	167
500	714	125	130	137	142	151	164	174	182	189	201
550	786	151	157	165	170	180	195	206	216	224	239
600	857	179	185	195	200	212	229	242	253	263	278
650	929	209	216	228	231	246	266	280	291	303	319
700	1000	242	249	260	267	283	306	322	333	346	365
750	1070	276	285	298	305	321	348	366	377	391	414
800	1140	314	324	337	345	362	392	411	426	439	465
850	1215	355	364	378	387	406	438	459	476	489	519
900	1285	396	408	424	434	453	486	510	531	543	574
950	1360	441	451	470	481	502	536	563	584	600	632
1000	1430	488	500	521	527	550	591	621	641	662	694
1100	1570	587	602	627	634	659	708	740	765	790	822
1200	1715	699	712	741	754	780	835	869	898	924	966

For this pipe size: V = 0.0252 × gpm; h_v = 9.858 × 10^{-6} gpm^2.
Figures in shaded area are laminar (viscous) flow.
For velocity data see page 3-20.

Note: No allowance has been made for age, difference in diameter, or any abnormal condition of interior surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation. It is recommended that for most commercial design purposes a safety factor of 15 to 20% be added to the values in the tables—see page 3-5.

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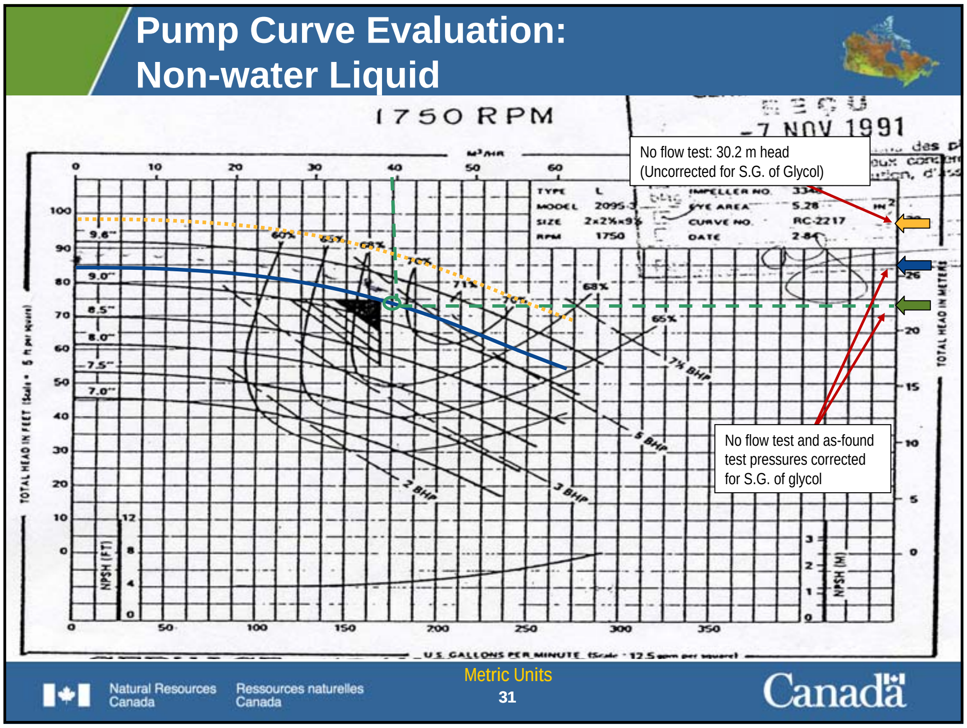
Pump Curve Evaluation:
Non-water Liquid
1750 RPM
-7 NOV 1991
No flow test: 30.2 m head
(Uncorrected for S.G. of Glycol)
No flow test and as-found
test pressures corrected
for S.G. of glycol
TOTAL HEAD IN FEET
TOTAL HEAD IN METERS
U.S. GALLONS PER MINUTE
Natural Resources Canada
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Metric Units
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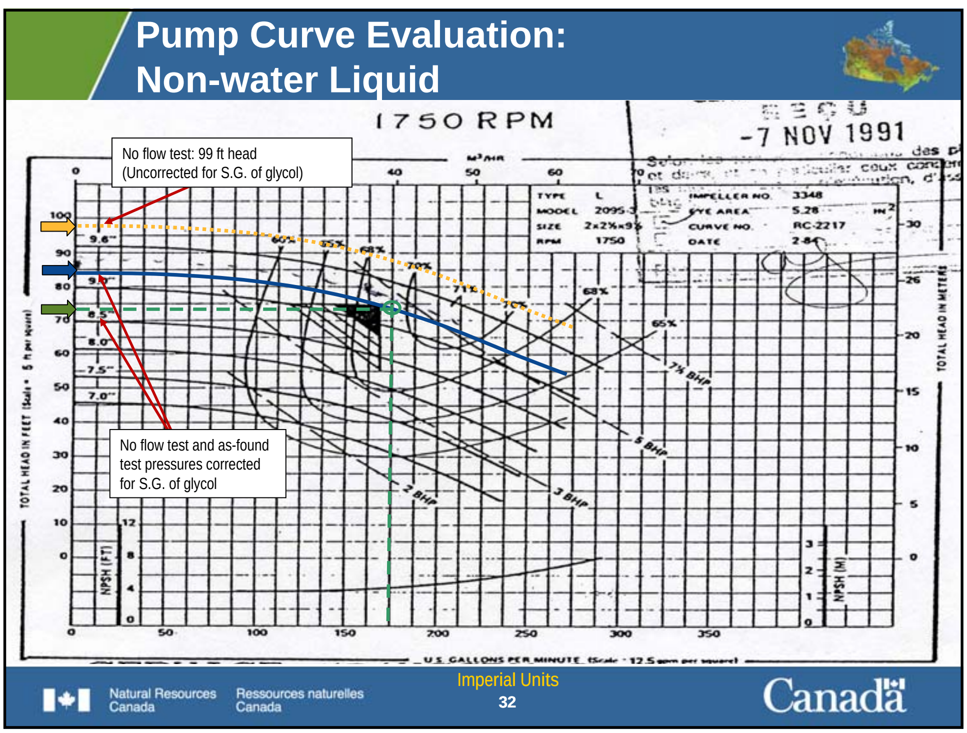
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Non-water Liquid
1750 RPM
-7 NOV 1991
No flow test: 99 ft head
(Uncorrected for S.G. of glycol)
No flow test and as-found
test pressures corrected
for S.G. of glycol
TOTAL HEAD IN FEET
TOTAL HEAD IN METERS
U.S. GALLONS PER MINUTE
Natural Resources Canada
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Imperial Units
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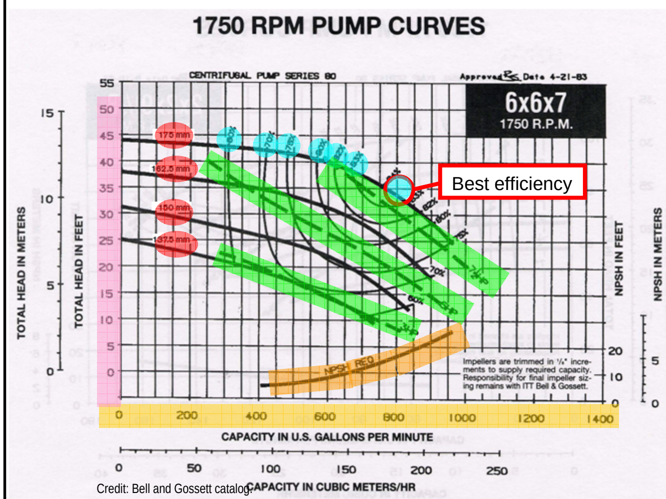
Typical Pump Performance Presentation



Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Metric Units

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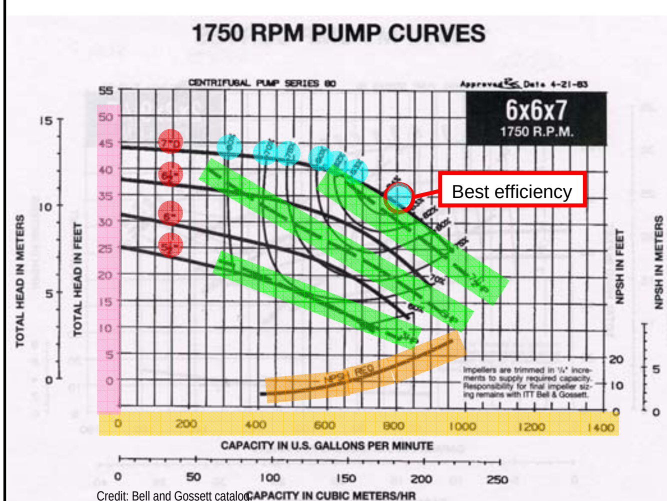
Typical Pump Performance Presentation



Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Imperial Units

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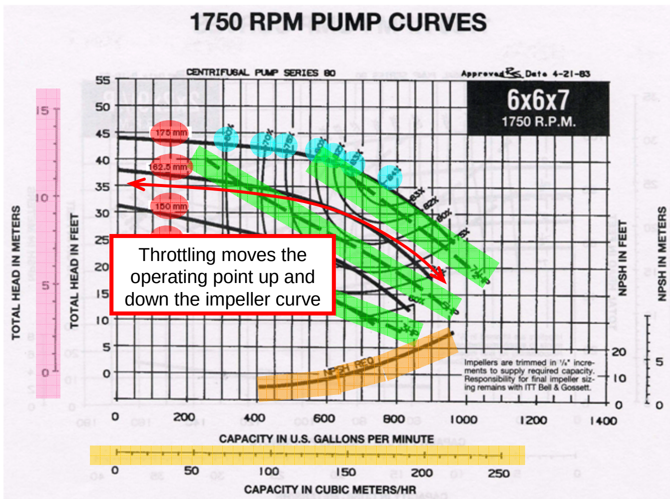
Typical Pump Performance Presentation



Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Metric Units

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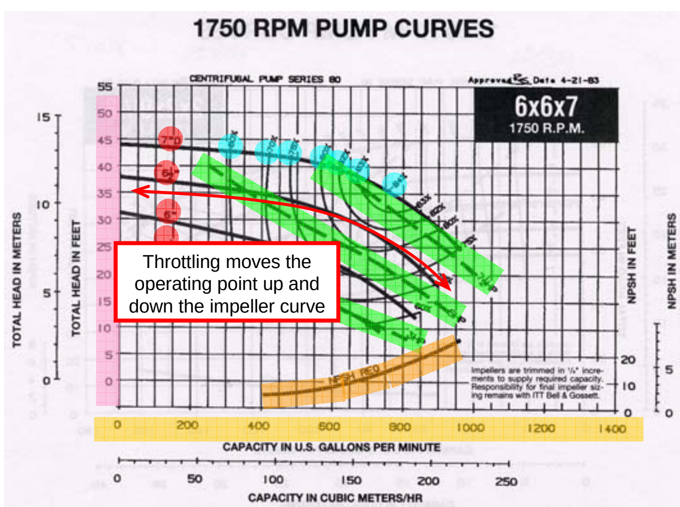
Canada

Typical Pump Performance Presentation



Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Imperial Units

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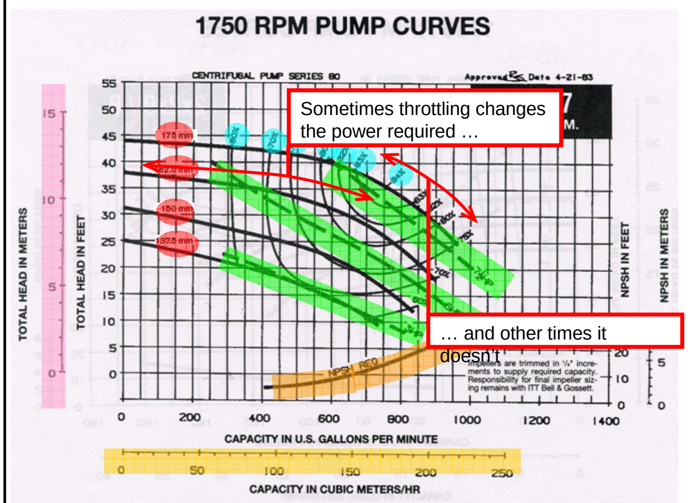
Typical Pump Performance Presentation



Credit: Bell and Gossett catalog.

Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

Metric Units

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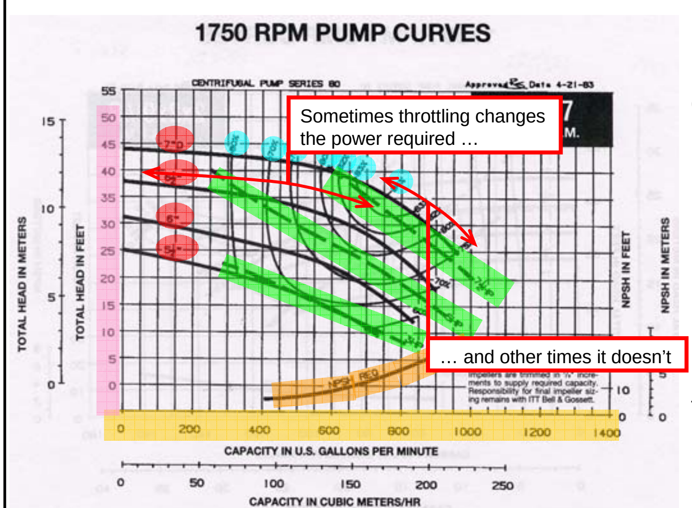
Natural Resources Canada Ressources naturelles Canada

Canada

Typical Pump Performance Presentation



Credit: Bell and Gossett catalog.

Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

Imperial Units

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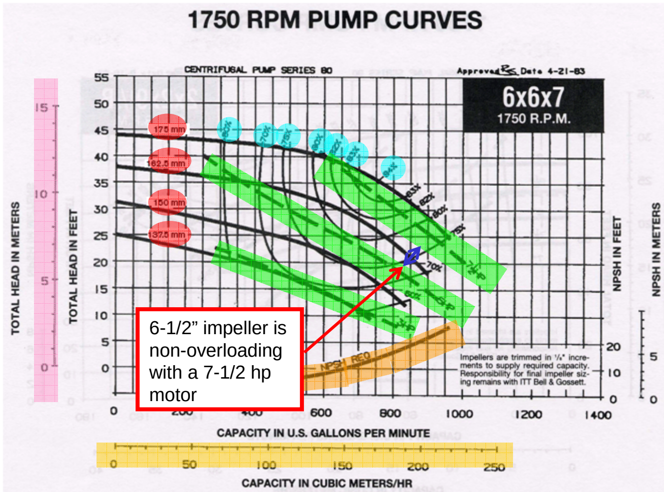
Natural Resources Canada Ressources naturelles Canada

Canada

Typical Pump Performance Presentation



Credit: Bell and Gossett catalog.

Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Metric Units
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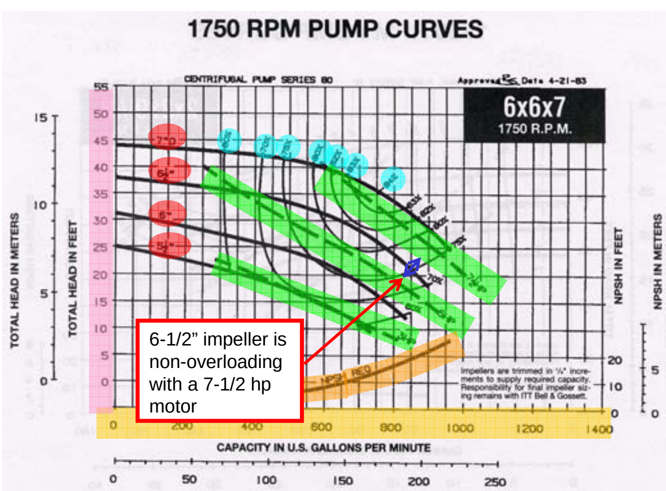
Canada

Typical Pump Performance Presentation



Credit: Bell and Gossett catalog.

Flow vs. Head for different Impeller Sizes

Percentage lines – Pump Efficiency

Long dashed lines – Pump Horse Power

NPSH – Inlet pressure for no cavitations

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Imperial Units
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Canada

Pump Affinity Laws

Advanced RCx Course

$$Q_2 = Q_1\left(\frac{N_2}{N_1}\right), H_2 = H_1\left(\frac{N_2}{N_1}\right) \quad \text{and } P_2 = P_1\left(\frac{N_2}{N_1}\right)^{2.5}$$

Where :

$N =$ Impeller speed, typically in revolutions per minute

$Q =$ Flow, typically in meters per hour

$H =$ Head, typically in meters of water column

$P =$ Power, in kW

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Metric Units

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Canada

Pump Affinity Laws

Advanced RCx Course

$$Q_2 = Q_1\left(\frac{N_2}{N_1}\right), H_2 = H_1\left(\frac{N_2}{N_1}\right)^2, \text{ and } BHP_2 = BHP_1\left(\frac{N_2}{N_1}\right)^{2.5}$$

Where:

$N =$ Impeller speed, typically in revolutions per minute

Q = Flow, typically in gallons per minute

H = Head, typically in feet water column

BHP = Brake horse power

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Imperial Units

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Canada

Pump Affinity Laws

Advanced RCx Course

Useful derived relationships:

$$Q_2 = Q_1\left(\frac{D_2}{D_1}\right), H_2 = H_1\left(\frac{Q_2}{Q_1}\right)^2, \text{ and } P_2 = P_1\left(\frac{Q_2}{Q_1}\right)^3$$

Where:

D = Impeller diameter

- Allow performance to be predicted up and down the system curve
- Allow new impeller curves to be generated based on an existing impeller curve

Pump Affinity Laws

Advanced RCx Course

Useful derived relationships:

$$Q_2 = Q_1\left(\frac{D_2}{D_1}\right), H_2 = H_1\left(\frac{Q_2}{Q_1}\right)^2, \text{ and } BHP_2 = BHP_1\left(\frac{Q_2}{Q_1}\right)^3$$

Where:

D = Impeller diameter

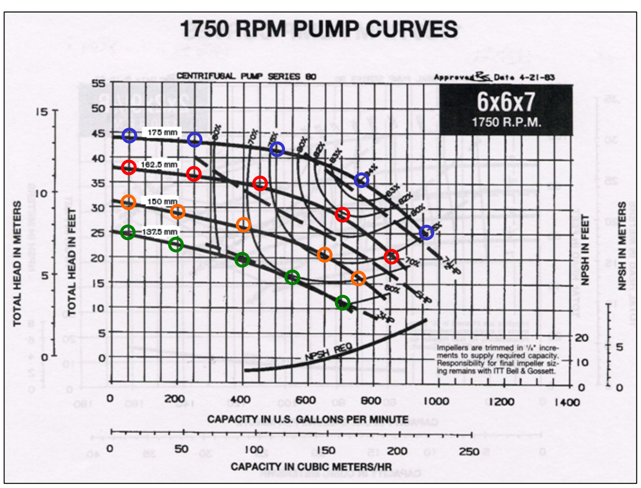
- Allow performance to be predicted up and down the system curve
- Allow new impeller curves to be generated based on an existing impeller curve

Applying the Affinity Laws To Predict Performance

Advanced RCx Course

- Approximate relationships
  - In most practical applications, the pump impeller is trimmed
  - Other dimensions do not change in proportion to the impeller changes
    - ➢Leakage losses impacted
    - ➢Hydraulic losses impacted

Applying the Affinity Laws To Predict Performance

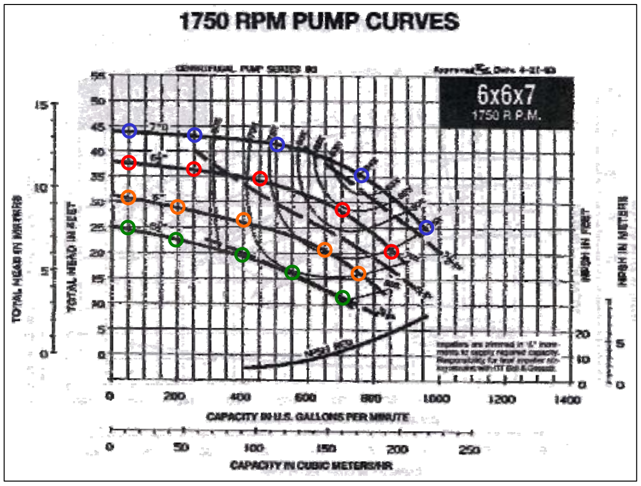


Credit: Bell and Gossett catalog.

Impeller Diameter	Flow	Head
O 175.0	216	7.9
	170	11.0
	114	12.8
	57	13.1
	11	13.4
O 162.5	200	6.7
	158	9.4
	105	11.0
	53	11.3
	10	11.6
O 150	185	5.8
	146	8.2
	97	9.4
	49	9.8
	10	10.1
O 137.5	169	5.2
	134	7.0
	89	8.2
	45	8.5
	9	8.5

Metric Units

Applying the Affinity Laws To Predict Performance



Impeller Diameter	Flow	Head
7.0	950	26
	750	36
	500	42
	250	43
	50	44
6.5	882	22
	696	31
	464	36
	232	37
	46	38
6.0	814	19
	643	27
	429	31
	214	32
	43	33
5.5	746	17
	589	23
	393	27
	196	28
	39	28

Credit: Bell and Gossett catalog.

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Imperial Units

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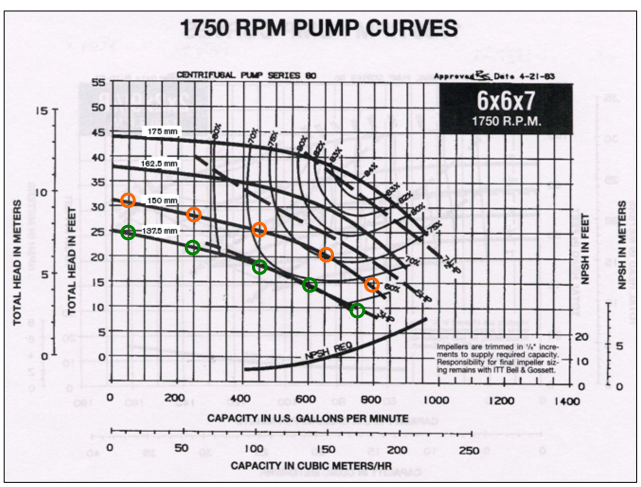
Canada

Applying the Affinity Laws To Predict Performance



Impeller Diameter	Flow	Head
150.0	182	4.3
	148	6.1
	102	7.6
	57	8.2
	11	9.4
137.5	166	3.7
	135	5.2
	94	6.7
	52	7.0
	10	8.2

Credit: Bell and Gossett catalog.

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Metric Units

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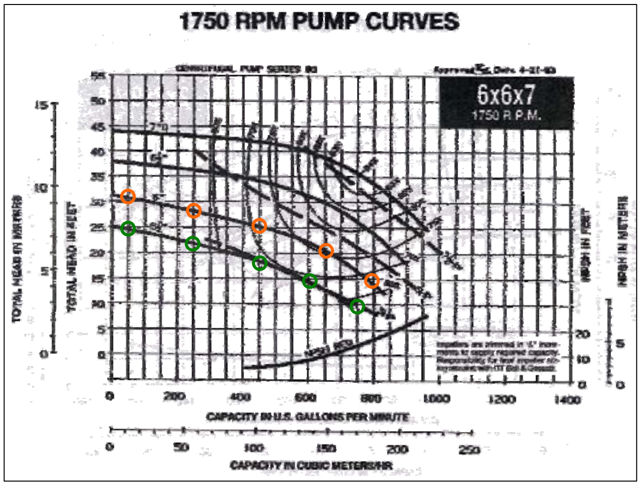
Applying the Affinity Laws To Predict Performance



Credit: Bell and Gossett catalog.

Impeller Diameter	Flow	Head
6.0	800	14
	650	20
	450	25
	250	27
	50	31
5.5	733	12
	596	17
	413	22
	229	23
	46	27

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Imperial Units

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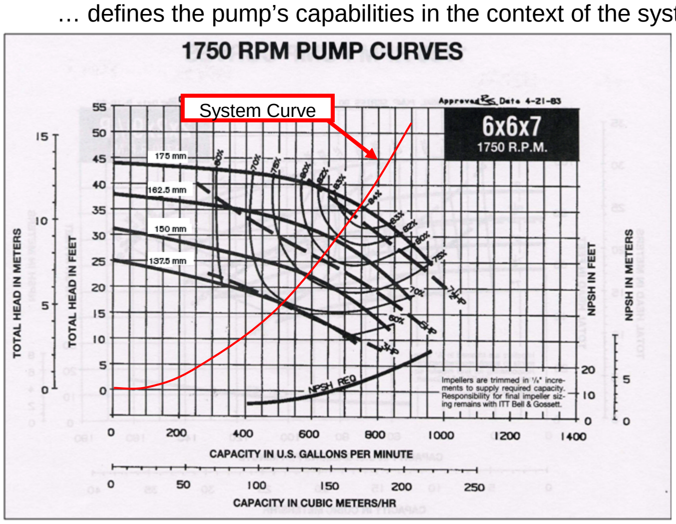
Canada

The System Curve…

… defines the pump's capabilities in the context of the system it serves



Credit: Bell and Gossett catalog.

- Approximately a "square law" relationship
  - Roots in the Darcey-Weisbach equation

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

H_L = Head loss

  - Experiments show the exponent to be more like 1.85 to 1.90

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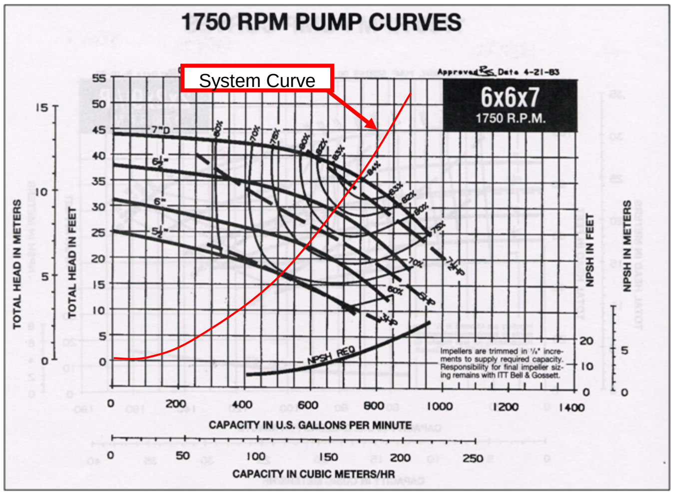
Metric Units

50

Canada

The System Curve…

… defines the pump's capabilities in the context of the system it serves



Credit: Bell and Gossett catalog.

- Approximately a "square law" relationship
  - Roots in the Darcey-Weisbach equation

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

H_L = Head loss

  - Experiments show the exponent to be more like 1.85 to 1.90

Imperial Units

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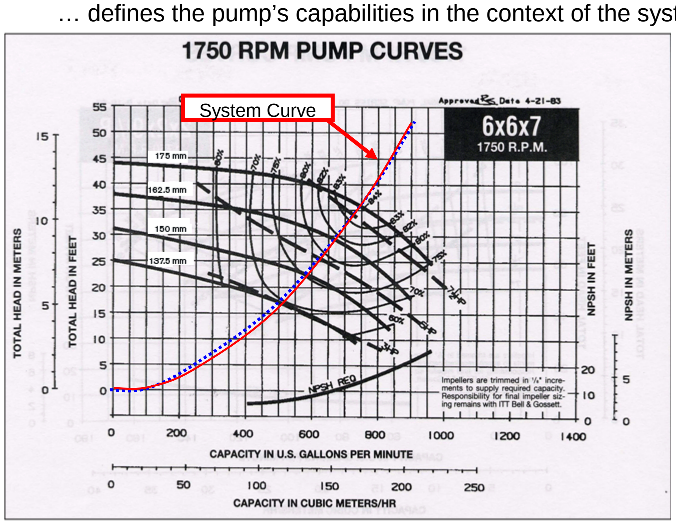
The System Curve…

… defines the pump's capabilities in the context of the system it serves



Credit: Bell and Gossett catalog.

Flow	Head
Exponent = 2	
170	11.0
114	4.9
57	1.2
23	0.5
Exponent = 1.9	
170	11.0
114	5.1
57	1.4
23	0.2
Exponent = 1.85	
170	11.0
114	5.2
57	1.4
23	0.3

Metric Units

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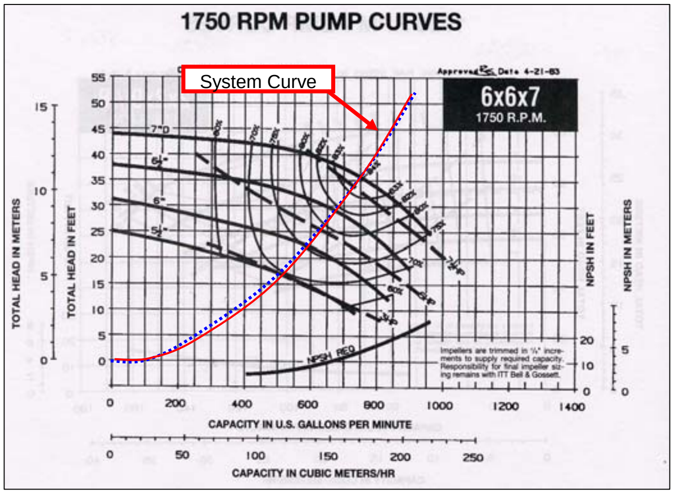
The System Curve…

… defines the pump's capabilities in the context of the system it serves



Flow	Head
Exponent = 2	
750	36.00
500	16.00
250	4.00
100	0.64
Exponent = 1.9	
750	36.00
500	16.66
250	4.46
100	0.78
Exponent = 1.85	
750	36.00
500	17.00
250	4.72
100	0.87

Credit: Bell and Gossett catalog.

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Imperial Units

53

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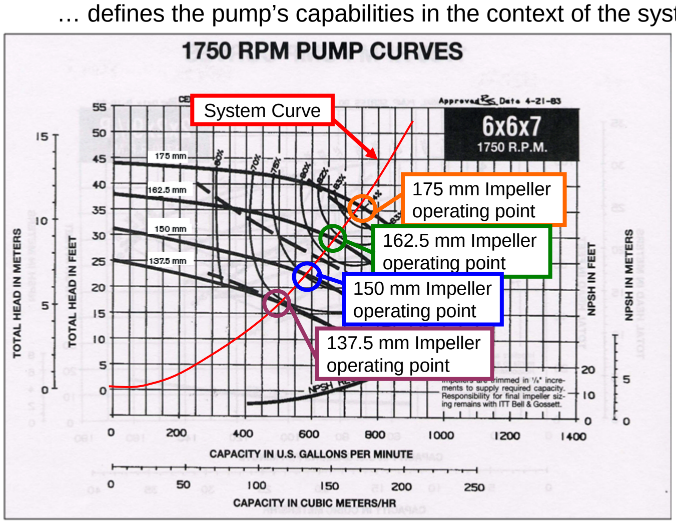
The System Curve…

… defines the pump's capabilities in the context of the system it serves



- Changing impeller size:
  - Moves up and down the system curve
  - Horsepower changes
  - Efficiency changes

Credit: Bell and Gossett catalog.

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Metric Units

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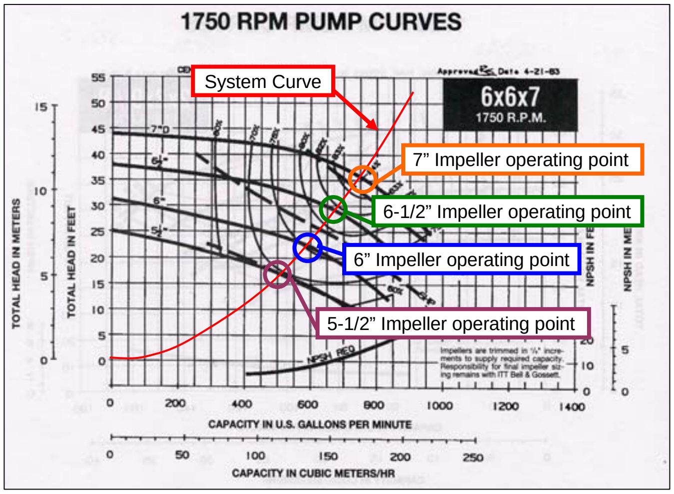
The System Curve…

… defines the pump's capabilities in the context of the system it serves



Credit: Bell and Gossett catalog.

- Changing impeller size:
  - Moves up and down the system curve
  - Horsepower changes
  - Efficiency changes

Imperial Units

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Common Open Pumping Systems

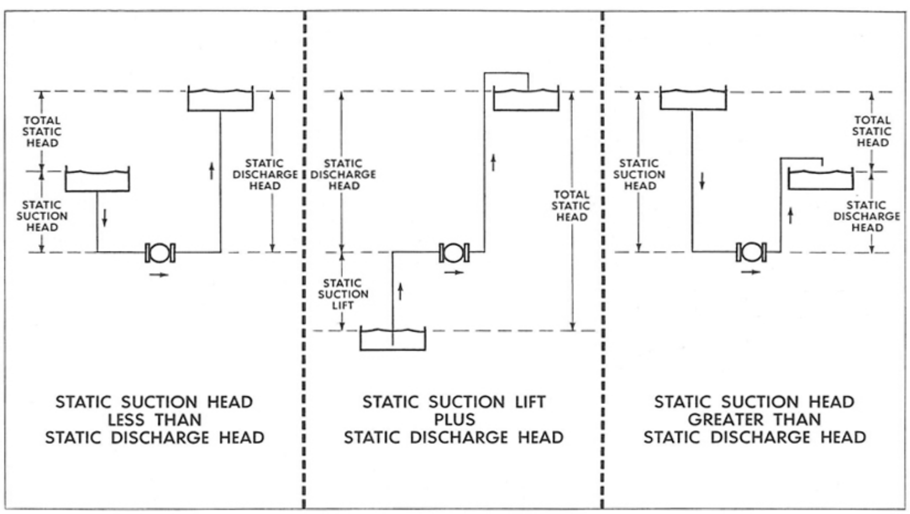

Figure 24 – Typical Open Systems

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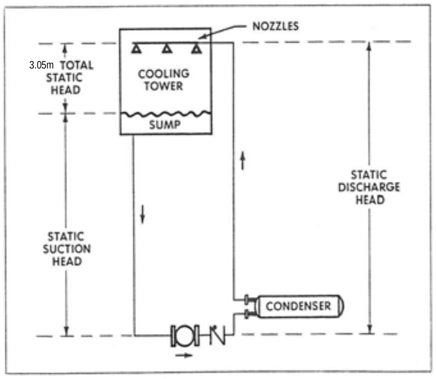
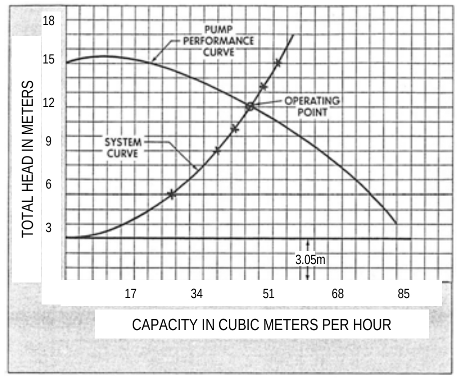
Open Cooling Tower Pumping System





m^3/h	0.0	26.1	37.5	42.0	Design 45.4	48.8	52.2
Pipe & valve pressure drop	0.0	3.0	6.1	7.6	9.1	10.7	12.2
+ Static energy head	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Total req'd head for flow	3.0	6.1	9.1	10.7	12.2	13.7	15.2

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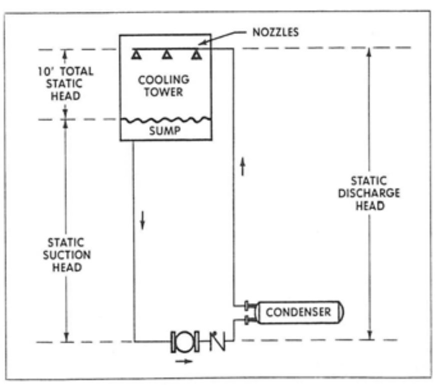
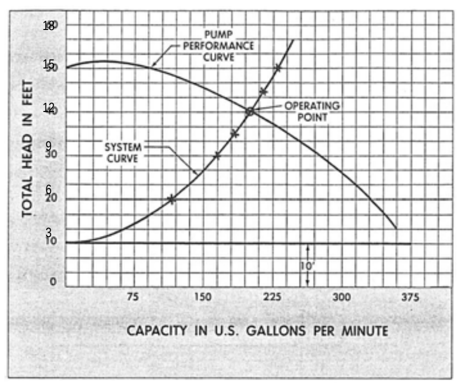
Open Cooling Tower Pumping System





GPM	0	115	165	185	Design 200	215	230
Pipe & valve pressure drop	0	10	20	25	30	35	40
+ Static energy head	10	10	10	10	10	10	10
Total req'd head for flow	10	20	30	35	40	45	50

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Imperial Units

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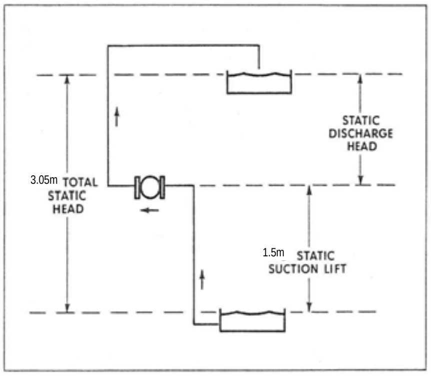
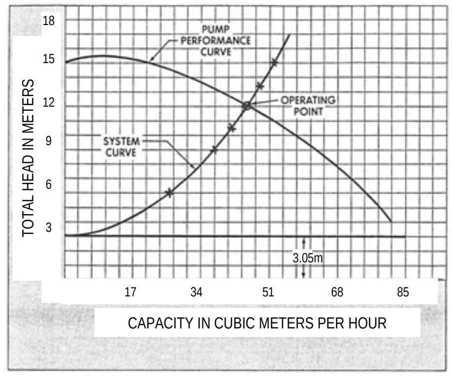
Suction Lift Pumping System





m^3/h	0.0	26.1	37.5	42.0	Design 45.4	48.8	52.2
Pipe & valve pressure drop	0.0	3.0	6.1	7.6	9.1	10.7	12.2
+ Static energy head	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Total req'd head for flow	3.0	6.1	9.1	10.7	12.2	13.7	15.2

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Metric Units

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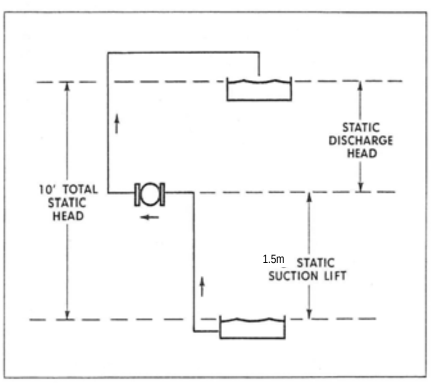
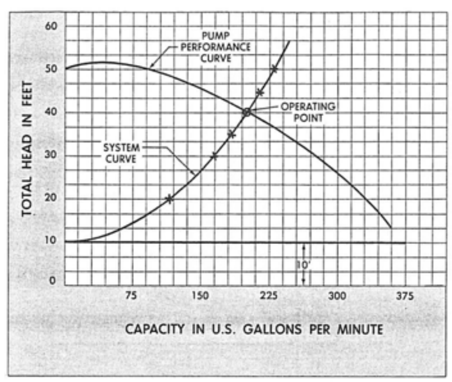
Suction Lift Pumping System





GPM	0	115	165	185	Design 200	215	230
Pipe & valve pressure drop	0	10	20	25	30	35	40
+ Static energy head	10	10	10	10	10	10	10
Total req'd head for flow	10	20	30	35	40	45	50

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Imperial Units

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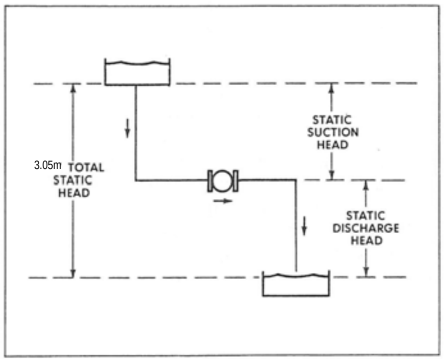
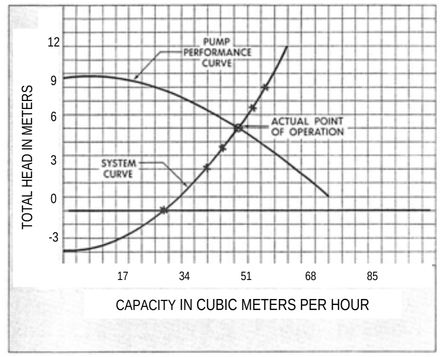
Booster Pump Application





m^3/h	0.0	26.1	37.5	42.0	Design 45.4	48.8	52.2
Pipe & valve pressure drop	0.0	3.0	6.1	7.6	9.1	10.7	12.2
+ Static energy head	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Total req'd head for flow	-3.0	0.0	3.0	4.6	6.1	7.6	9.1

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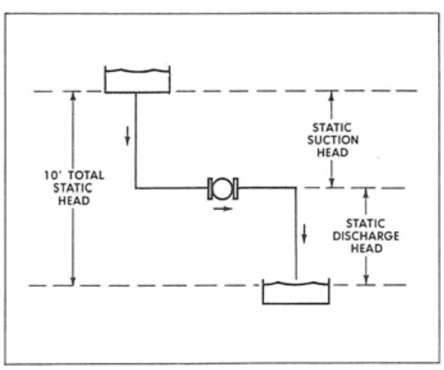
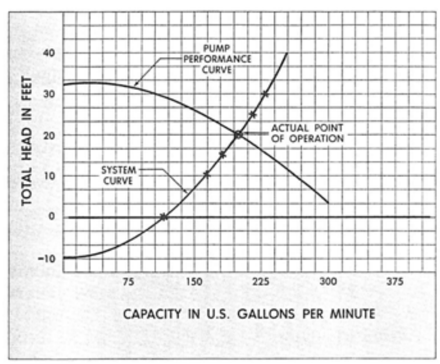
Booster Pump Application





GPM	0	115	165	185	Design 200	215	230
Pipe & valve pressure drop	0	10	20	25	30	35	40
+ Static energy head	-10	-10	-10	-10	-10	-10	-10
Total req'd head for flow	-10	0	+10	+15	+20	+25	+30

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Imperial Units

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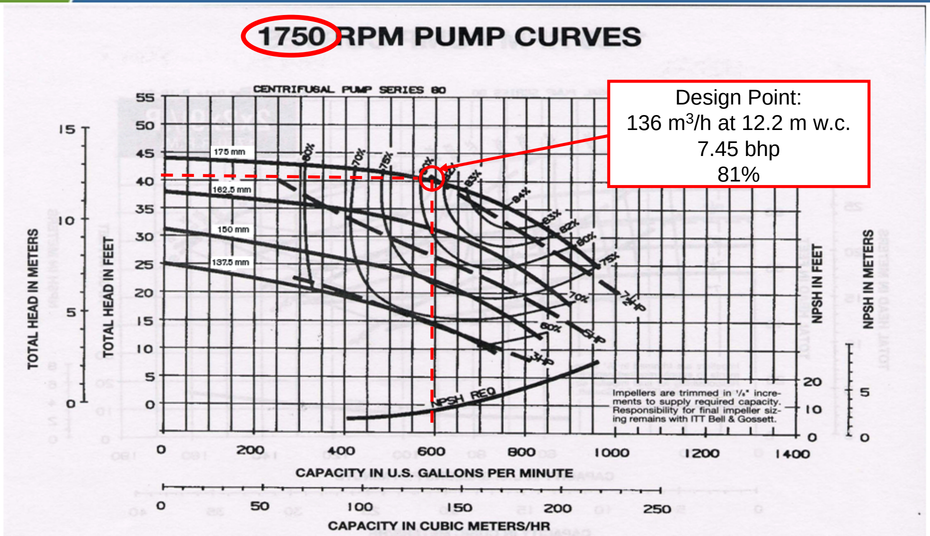
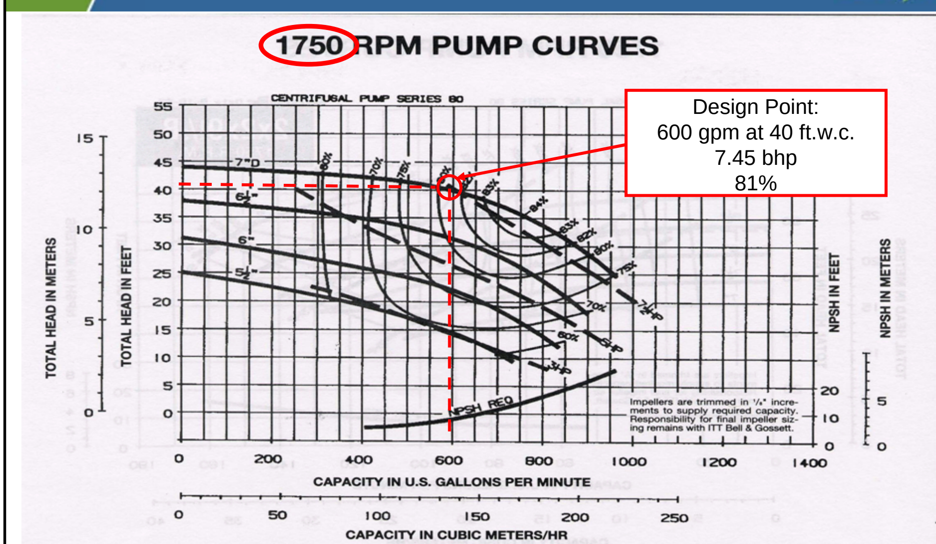
Speed Change vs. Throttling

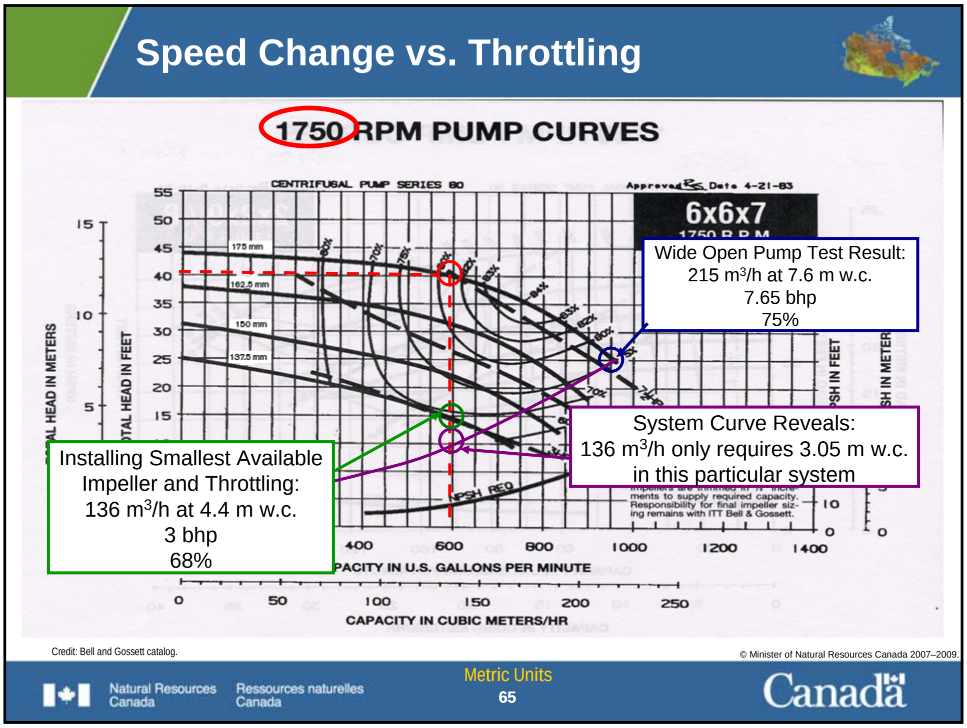


Credit: Bell and Gossett catalog.

Speed Change vs. Throttling



Credit: Bell and Gossett catalog.


Speed Change vs. Throttling
1750 RPM PUMP CURVES
CENTRIFUGAL PUMP SERIES 80
6x6x7
Wide Open Pump Test Result:
215 m³/h at 7.6 m w.c.
7.65 bhp
75%
System Curve Reveals:
136 m³/h only requires 3.05 m w.c.
in this particular system
Installing Smallest Available
Impeller and Throttling:
136 m³/h at 4.4 m w.c.
3 bhp
68%
CAPACITY IN CUBIC METERS/HR
Credit: Bell and Gossett catalog.
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Metric Units
65
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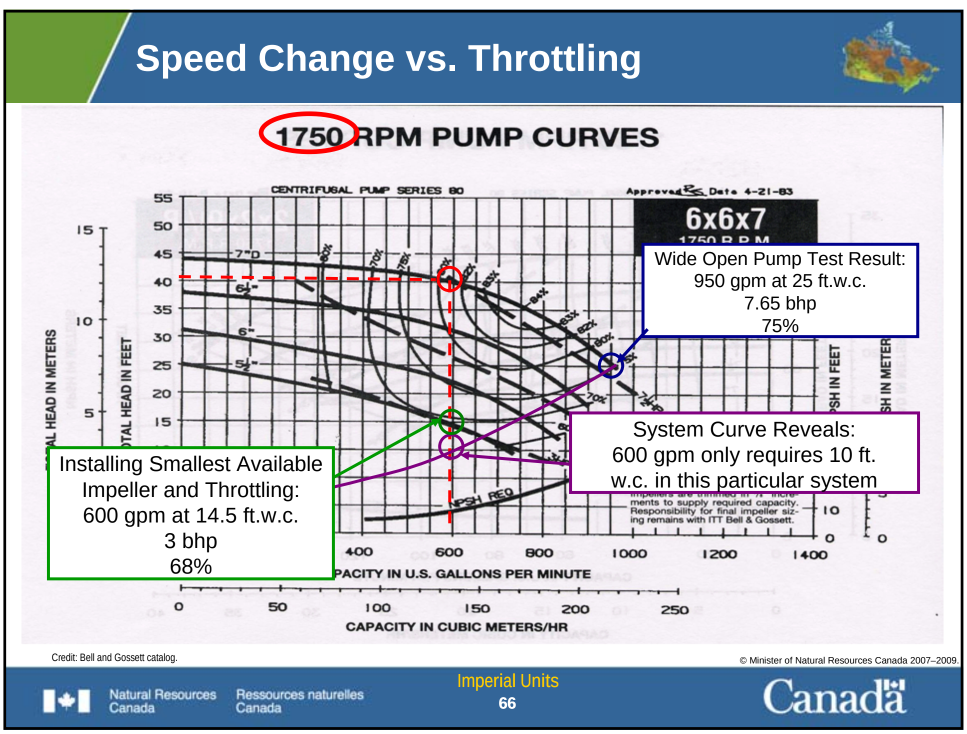
Speed Change vs. Throttling
1750 RPM PUMP CURVES
CENTRIFUGAL PUMP SERIES 80
6x6x7
Wide Open Pump Test Result:
950 gpm at 25 ft.w.c.
7.65 bhp
75%
System Curve Reveals:
600 gpm only requires 10 ft.
w.c. in this particular system
Installing Smallest Available
Impeller and Throttling:
600 gpm at 14.5 ft.w.c.
3 bhp
68%
CAPACITY IN CUBIC METERS/HR
Credit: Bell and Gossett catalog.
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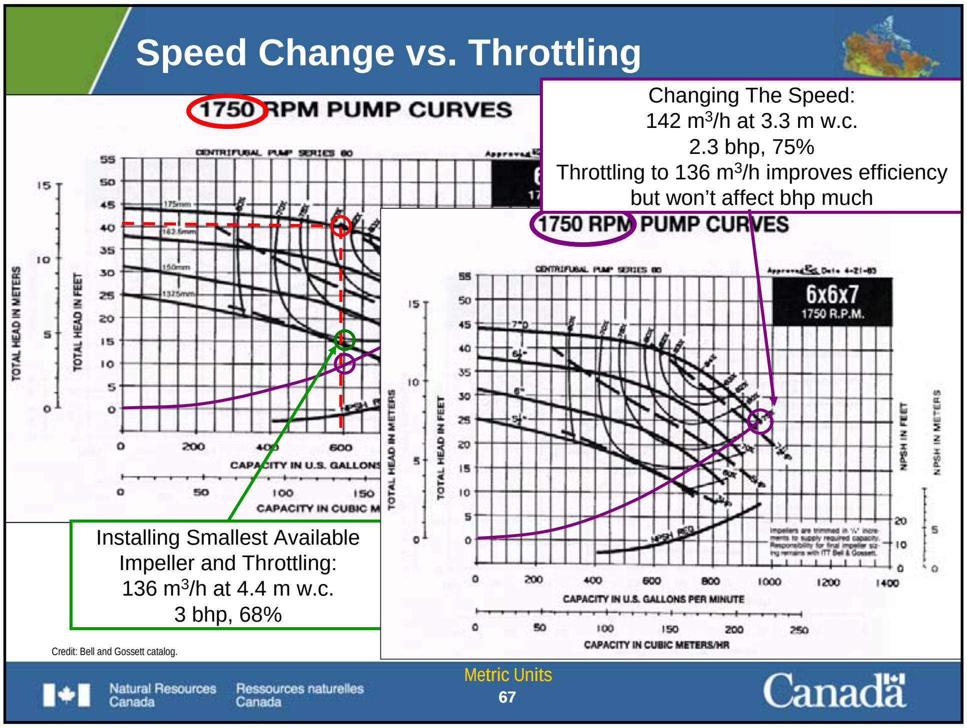
Imperial Units
66
Canada


Speed Change vs. Throttling
1750 RPM PUMP CURVES
Changing The Speed:
142 m3/h at 3.3 m w.c.
2.3 bhp, 75%
Throttling to 136 m3/h improves efficiency
but won't affect bhp much
1750 RPM PUMP CURVES
6x6x7
1750 R.P.M.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR
NPSH IN FEET
NPSH IN METERS
Installing Smallest Available
Impeller and Throttling:
136 m3/h at 4.4 m w.c.
3 bhp, 68%
Credit: Bell and Gossett catalog.
Metric Units
67
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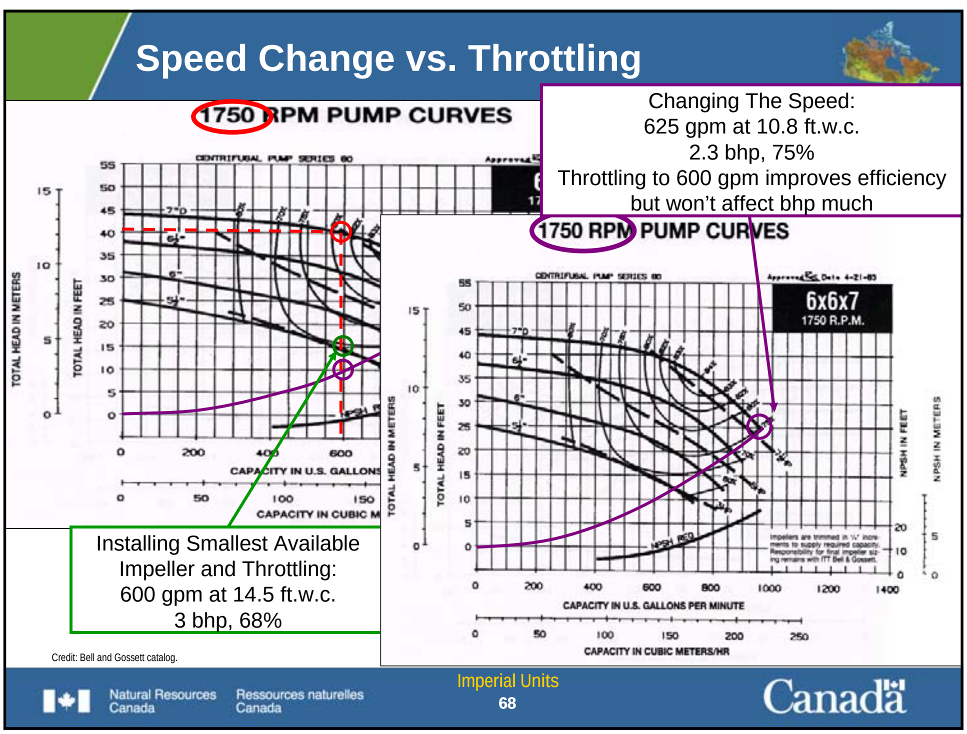
Speed Change vs. Throttling
1750 RPM PUMP CURVES
Changing The Speed:
625 gpm at 10.8 ft.w.c.
2.3 bhp, 75%
Throttling to 600 gpm improves efficiency
but won't affect bhp much
1750 RPM PUMP CURVES
6x6x7
1750 R.P.M.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR
NPSH IN FEET
NPSH IN METERS
Installing Smallest Available
Impeller and Throttling:
600 gpm at 14.5 ft.w.c.
3 bhp, 68%
Credit: Bell and Gossett catalog.
Imperial Units
68
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One of our Obvious Indicators…

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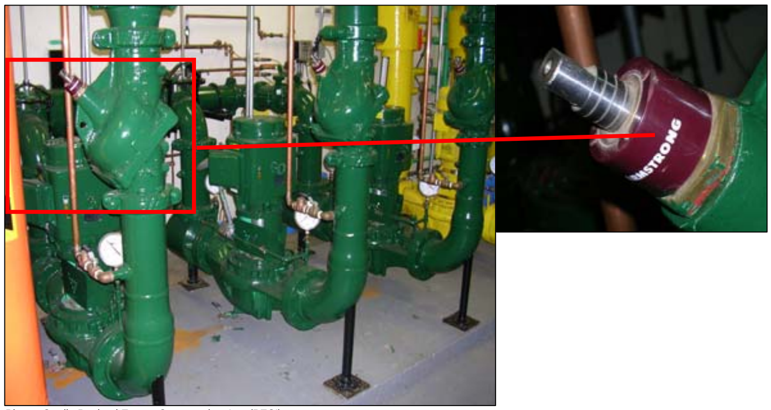
…a throttled valve on the discharge of the condenser water pump



Photos Credit: Portland Energy Conversation, Inc. (PECI)

The Pump Nameplate Data vs. Our Head Assessment Also Makes Us Wonder

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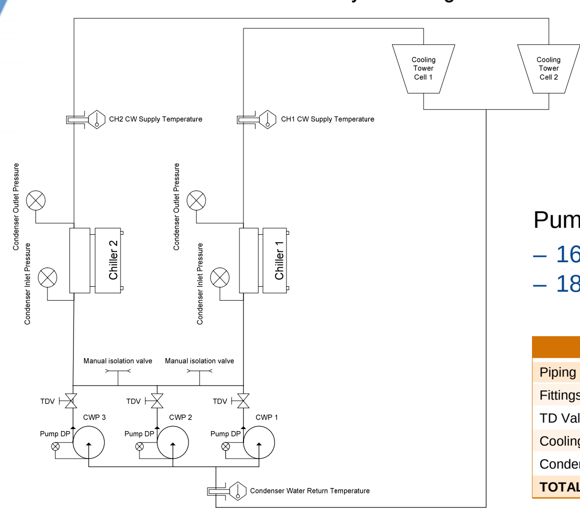
Condenser Water System Diagram



Pump Nameplate

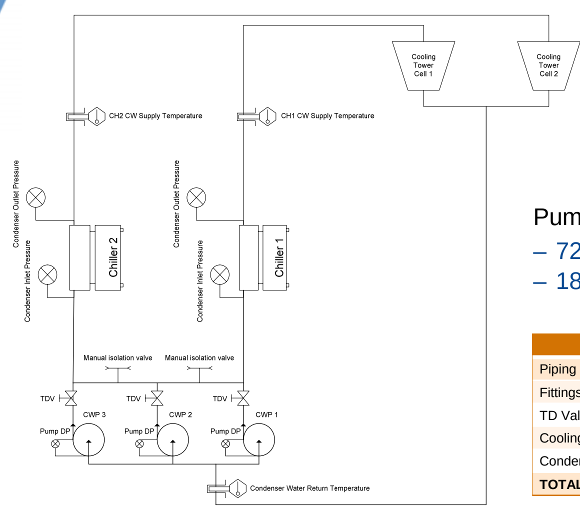
- 164 m³/h
- 18 m w.c.

Item	Minimum	Maximum
Piping	1.6	2.2
Fittings	0.2	0.2
TD Valve	1.2	1.5
Cooling Tower	2.4	3.7
Condenser bundle	4.0	4.9
TOTAL	**9.4**	**12.5**

Metric Units

The Pump Nameplate Data vs. Our Head Assessment Also Makes Us Wonder

Condenser Water System Diagram



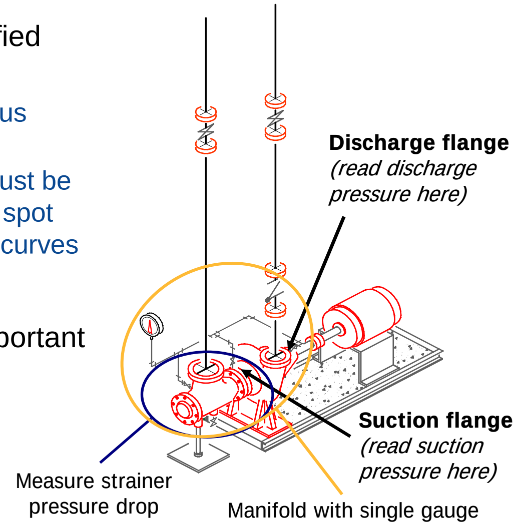
Pump Nameplate

- 720 gpm
- 18 ft. w.c.

Item	Minimum	Maximum
Piping	5.4	7.2
Fittings	0.6	0.8
TD Valve	4	5
Cooling Tower	8	12
Condenser bundle	13	16
TOTAL	**31**	**41**

Performing a Pump Test

- Pump curves are certified performance
  - Flow vs. head for various impeller sizes
  - Differential pressure must be measured at the same spot used to develop pump curves
- Use the same gauge
- Inlet conditions are important
  - Strainer condition
  - Velocity profile



As-found Conditions

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- Prior to making any adjustments to the system, record the current operating conditions.
  - Record suction and discharge pressures
  - Mark current position of throttling valve so that the system can be returned to the as-found operating parameters once the test is complete.
  - Measure motor amperage

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No Flow Test

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- The No Flow test will verify the actual impeller installed in the pump.
  - Turn off the pump at the motor control centre (MCC)
  - Close the throttling valve completely and turn the motor back on. Note the pump should not operate for more than 5 minutes in a no flow condition.
  - Record suction and discharge pressure to determine head developed by the pump
  - Plot the head value on the pump curve
  - Verify that nameplate impeller is installed and use that impeller curve for the analysis. If the No Flow test reveals that a different impeller is installed, develop a pump curve for this impeller via interpolation between the two closest impeller curves.

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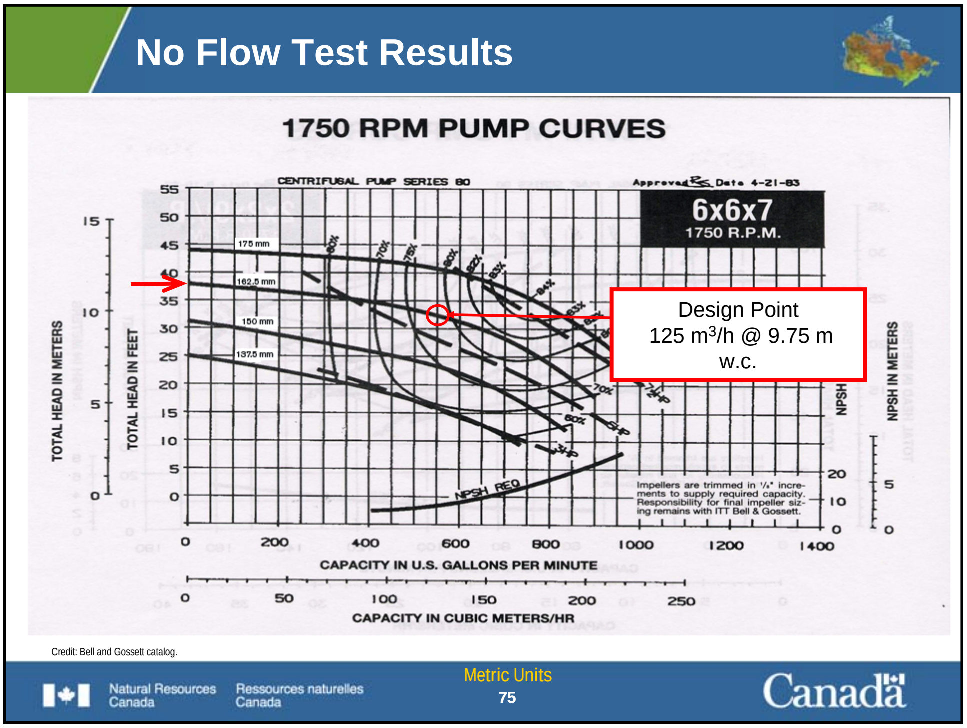
No Flow Test Results
1750 RPM PUMP CURVES
CENTRIFUGAL PUMP SERIES 80
6x6x7
1750 R.P.M.
Design Point
125 m³/h @ 9.75 m w.c.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN METERS
NPSH REQ
175 mm
162.5 mm
150 mm
137.5 mm
Impellers are trimmed in ¹/₈" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR
Credit: Bell and Gossett catalog.
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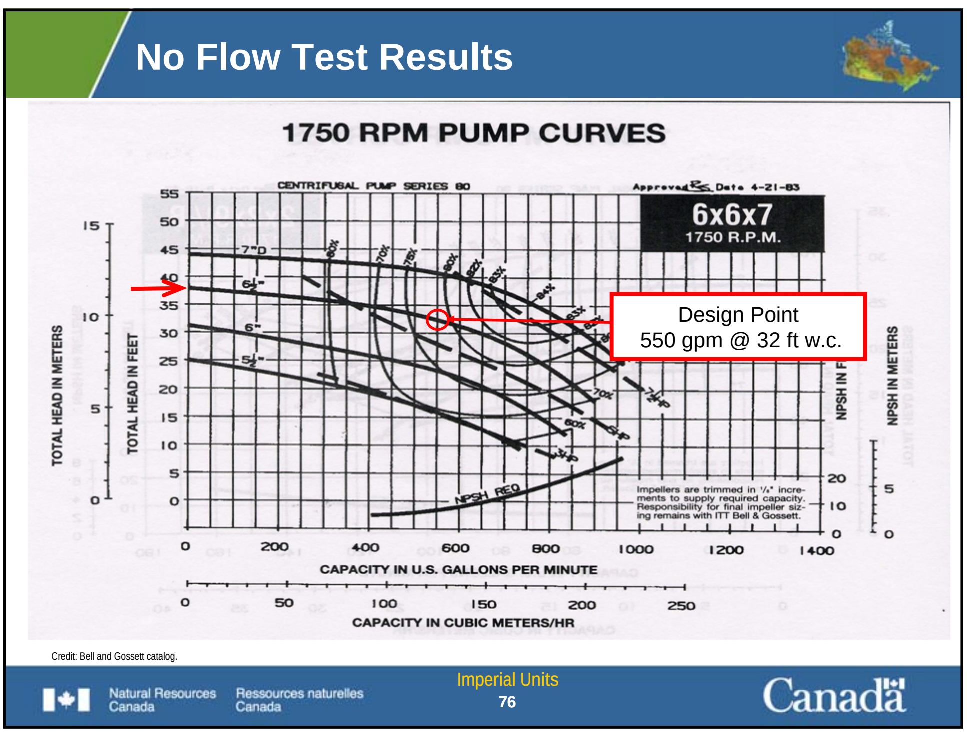
Metric Units
75
Canada


No Flow Test Results
1750 RPM PUMP CURVES
CENTRIFUGAL PUMP SERIES 80
6x6x7
1750 R.P.M.
Design Point
550 gpm @ 32 ft w.c.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN METERS
NPSH REQ
Impellers are trimmed in ¹/₈" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR
Credit: Bell and Gossett catalog.
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Imperial Units
76
Canada

Wide Open Test

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- The Wide Open test will be used to develop the system operating curve with the throttling valve completely open.
  - Turn off the pump at the MCC.
  - Open the throttling valve completely and turn the motor back on.
  - Record suction and discharge pressure to determine head developed by the pump.
  - Plot the head value on the pump curve established during the No Flow test. This will be the basis for the system operating curve.
  - Ensure that all valves on the loop are open, and bypass valves are closed.

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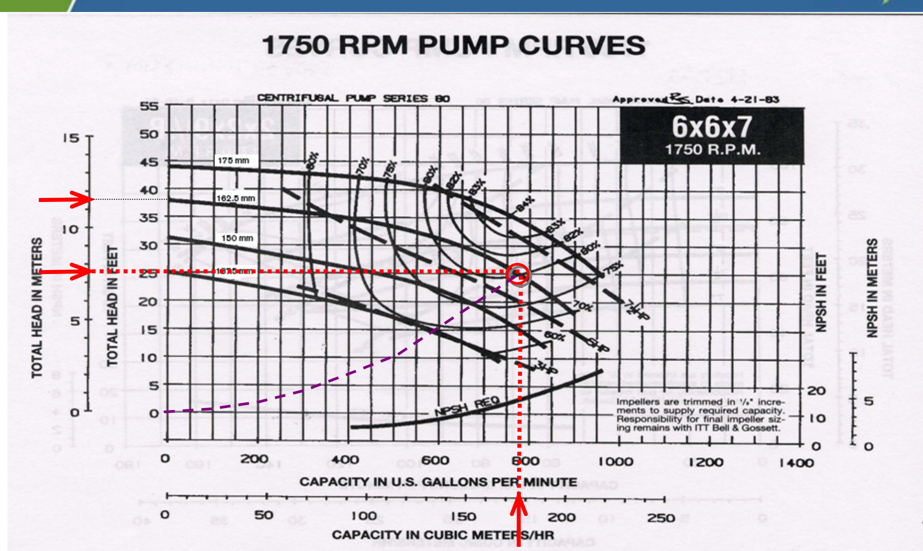
Wide Open Test Results



Credit: Bell and Gossett catalog.

Metric Units

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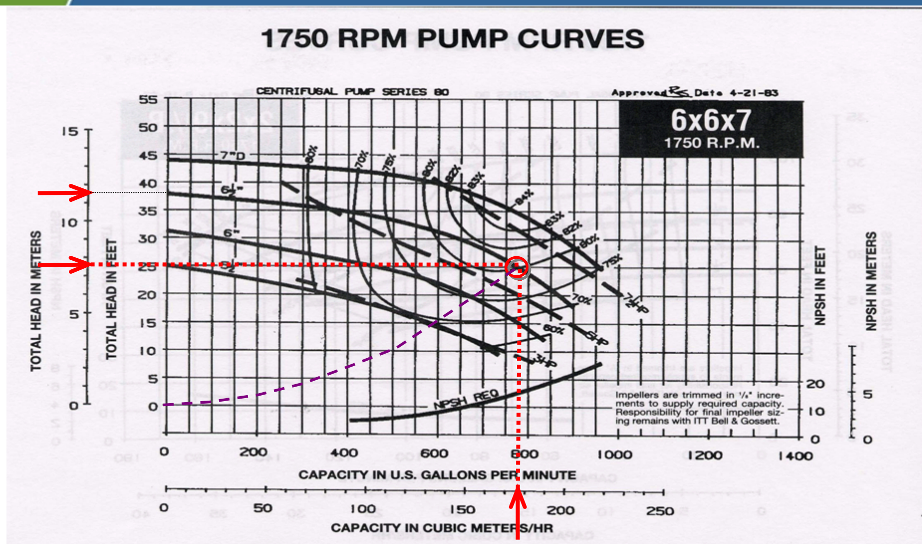
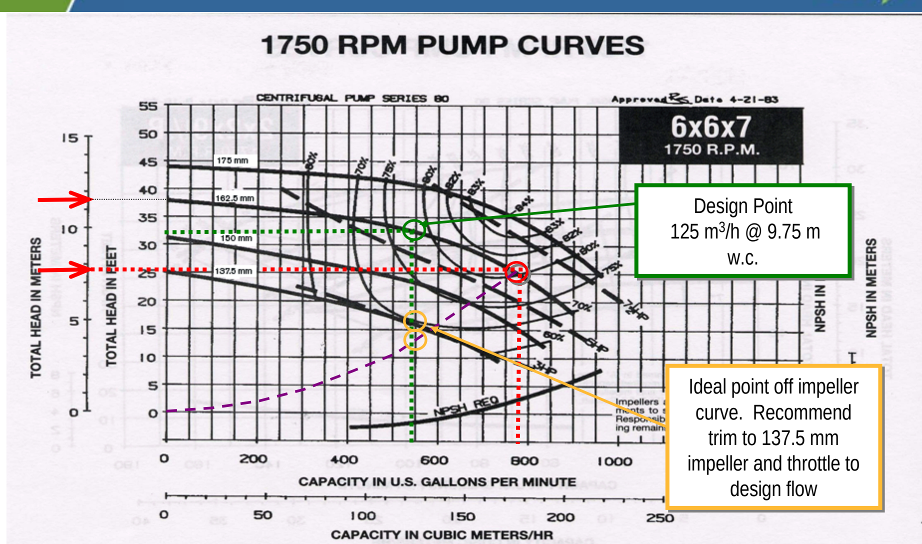
Wide Open Test Results



Credit: Bell and Gossett catalog.

Imperial Units

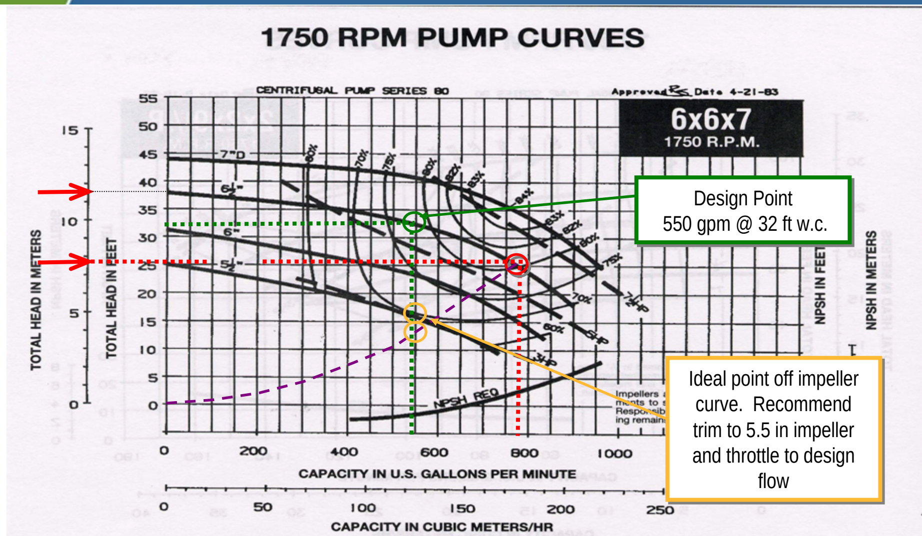
Plotting the Results



Credit: Bell and Gossett catalog.

Metric Units

Plotting the Results



Credit: Bell and Gossett catalog.

Pump Energy: A Function of Head and Flow

Advanced RCx Course

$$P_{PUMP} = \frac{Q \text{ x } h}{K \text{ x } \eta_{PUMP} \text{ x } \eta_{MOTOR}}$$

Where:

P_{PUMP} = Pumping power in kW

Q = Flow rate in m^3/h

h = Head in m w.c.

K = Units conversion constant = 367.68

η_{PUMP} = Pump efficiency

η_{MOTOR} = Motor efficiency

Photo Credit: Armstrong Website.

Pump Energy: A Function of Head and Flow

Advanced RCx Course

$$P_{PUMP} = \frac{Q \times h}{K \times \eta_{PUMP} \times \eta_{MOTOR}}$$

Where:

P_{PUMP} = Pumping horsepower

Q = Flow rate in gallons per minute

h = Head in ft.w.c.

K = Units conversion constant = 3,960

η_{PUMP} = Pump efficiency

η_{MOTOR} = Motor efficiency

Photo Credit: Armstrong Website.

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Imperial Units

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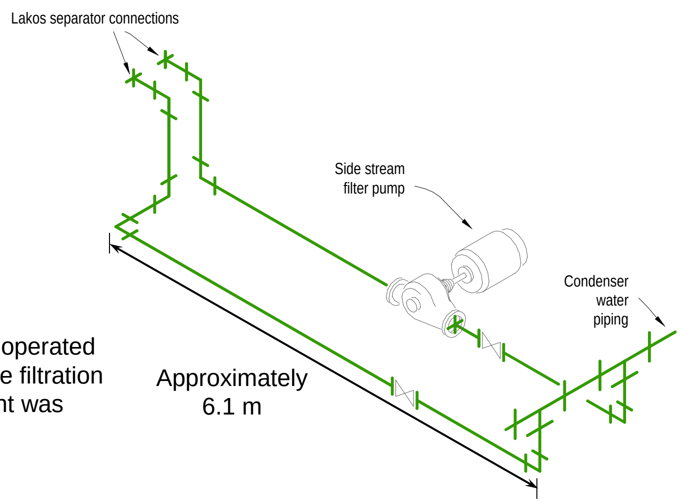
Canada

If It's Not Throttled, There Still May Be Opportunity

Pump rated 273 m^3/h at 12.2 m w.c.



The pump operated 24/7 but the filtration requirement was seasonal

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Metric Units

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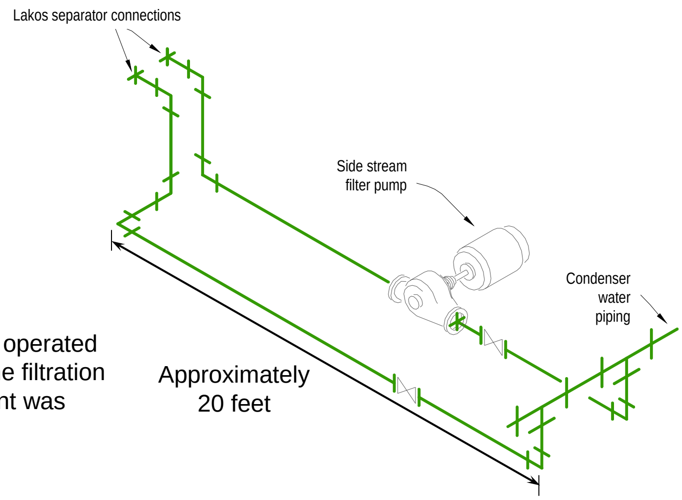
If It's Not Throttled, There Still May Be Opportunity

Pump rated 1,200 gpm at 40 ft.w.c.

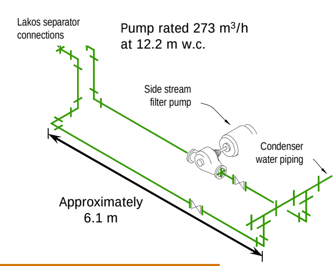


The pump operated 24/7 but the filtration requirement was seasonal

A Side Stream Filter Pump Example

Advanced RCx Course

- Bracket the potential based on estimates at two extremes
- Quick field/office estimate identifies the savings potential

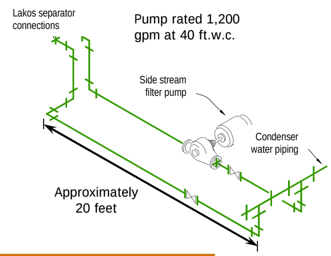


Item	Projected Pump Head – m w.c.		Comments
	Minimum	Maximum	
Lakos separator	3.0	8.4	Minimum requirement based on a guess in the field. Maximum pressure requirement based on worst case web site information.
Piping	2.0	2.0	Equivalent feet based on the piping loop: factor of 2 for fitting losses all taken at 0.04 m w.c. per linear meter.
TOTAL	**5.1**	**10.4**	

A Side Stream Filter Pump Example

Advanced RCx Course

- Bracket the potential based on estimates at two extremes
- Quick field/office estimate identifies the savings potential



Item	Projected Pump Head – ft. w.c.		Comments
	Minimum	Maximum	
Lakos separator	10.0	27.7	Minimum requirement based on a guess in the field. Maximum pressure requirement based on worst case web site information.
Piping	6.4	6.4	Equivalent feet based on the piping loop: factor of 2 for fitting losses all taken at 4 ft. w.c. head requirement per 100 ft. of pipe.
TOTAL	**16.8**	**34.1**	

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Imperial Units

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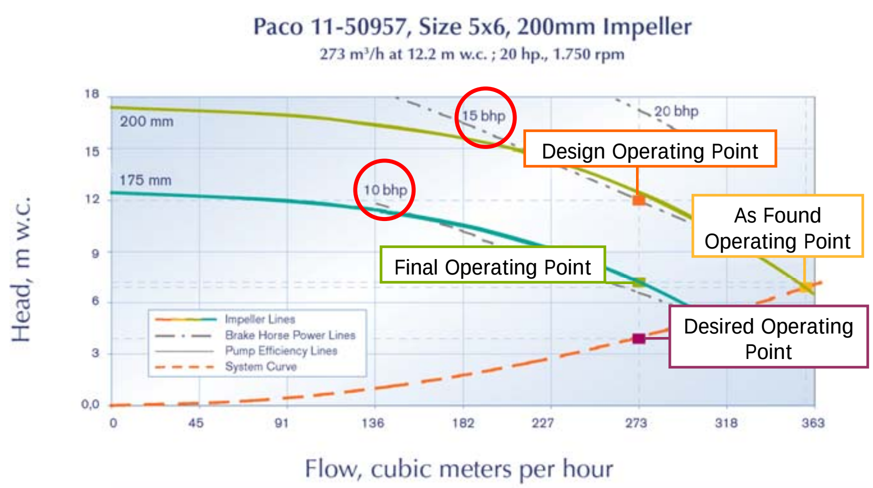
The Results of Recommissioning



Note: The information on this pump curve was reproduced from the manufacturers certified performance curves for the purposes of analysis and illustration. To verify certified performance for this pump, refer to the manufacturers certified performance curve.

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Metric Units

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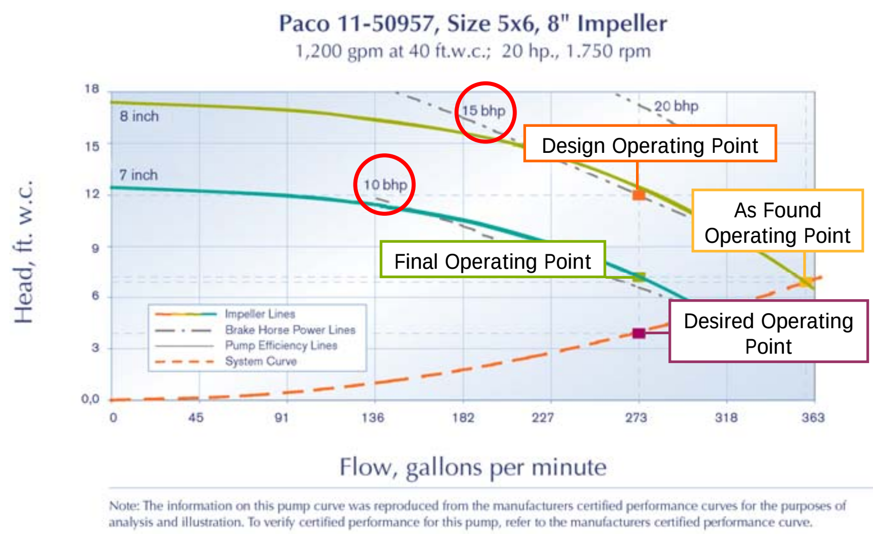
The Results of Recommissioning



Imperial Units

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Pumping Opportunities for Ice Rinks

Advanced RCx Course

- In most arenas, the rink ice is cooled by a brine (or glycol) solution circulated in a network of pipes that are embedded in a concrete slab.
- Generally, a constant-speed pump circulates the brine (coolant) through this network of pipes; making two passes through the slab before returning to the refrigeration evaporator to be cooled again
- The brine pump often consumes over 15% of the refrigeration system's total energy consumption

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Pumping Opportunities for Ice Rinks

- The energy consumed by the refrigeration system and the brine pump may be minimized by the use of:
  - Two-speed motors running at full speed during the day and at low speed during unoccupied hours (night)
  - Variable-speed motors controlled by the brine temperature differential
  - Two or more pumps controlled by the temperature change of the brine as it passes through the slab or an occupied-unoccupied (day-night) timer
  - Brine circuits that complete four or more passes through the slab

Pumping Opportunities for Ice Rinks

- These strategies reduce the total brine flow rate, corresponding to a reduction in required pumping power
- Reducing pump power has both direct and indirect impacts
  - Energy consumption of the brine pump and the refrigeration system can be reduced between 3% to 14% of the total system consumption depending on control strategy implemented
  - Multi-pass networks may affect the uniformity of the ice temperature
  - Any reduction in brine flow rate influences the performance of the refrigeration system

Building Operation Optimization

Advanced Recommissioning (RCx) Course

Investigation Phase Activities
(In-depth Building Investigation)

Developed by Portland Energy Conservation, Inc.

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Adapted by Natural Resources Canada's CanmetENERGY

www.canmetenergy.nrcan.gc.ca

Activities

- **Part 1:** Review system diagram and pump test analysis
  - Use a system diagram for a chilled water plant to help analyze observed pump operating parameters under various control sequences
- **Part 2:** Perform a comprehensive pumping system analysis
  - Data from a past project and the concepts discussed previously will be used to fully evaluate the savings potential for a pumping system

Complex Pumping System

Advanced RCx Course

- Chilled water plant with ice storage
- Three distinct operating configurations
  - Conventional chilled water distribution
  - Ice storage water distribution
  - Recharging ice storage tanks

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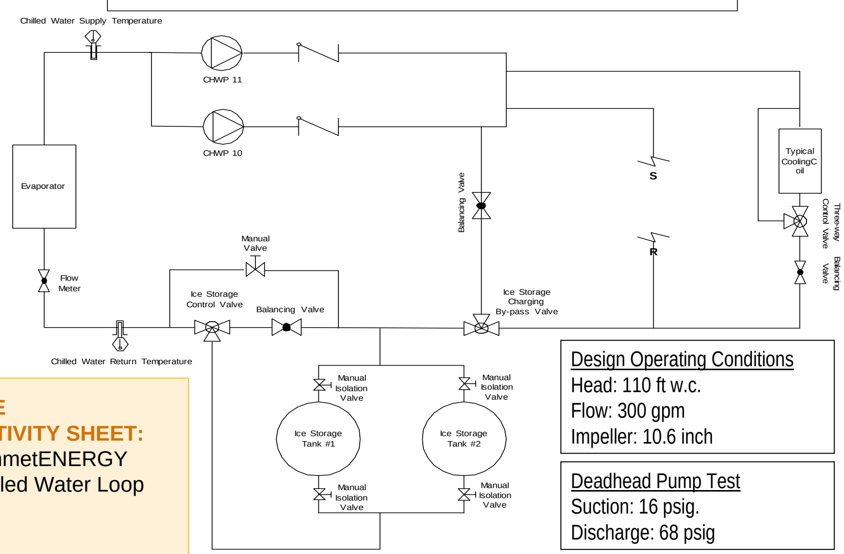
Chilled Water Plant with Ice Storage

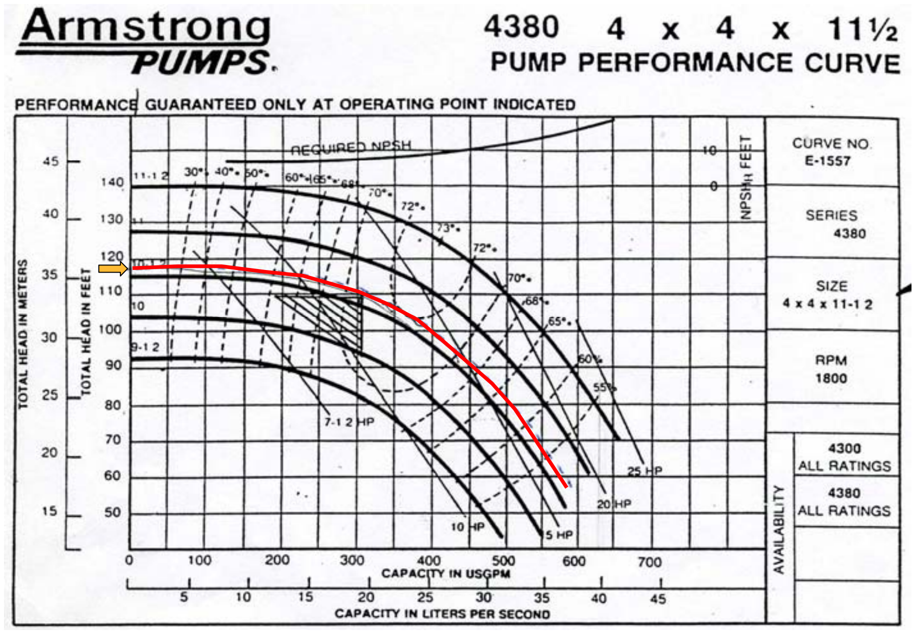
Varennes Chilled Water Loop



Design Operating Conditions
Head: 110 ft w.c.
Flow: 300 gpm
Impeller: 10.6 inch

Deadhead Pump Test
Suction: 16 psig.
Discharge: 68 psig

SEE ACTIVITY SHEET:
CanmetENERGY Chilled Water Loop



SEE ACTIVITY SHEET:
Armstrong Pumps – Pump Performance Curve (4380 4 x 4 x 11½)

Testing Configurations

Advanced RCx Course

- **Test #1** – Pump operation when operating as a conventional chilled water distribution system and full flow the cooling coils
- **Test #1A** – Pump operation when operating as a conventional chilled water distribution system and flow by-passing the cooling coils
- **Test #2** – Pump operation when ice storage is being used to meet the load
- **Test #3** – Pump operation when the chiller is used to recharge the ice storage tanks
- **Test #3A** – Pump operation when the chiller is used to recharge the ice storage tanks and by-pass balancing valve is wide open

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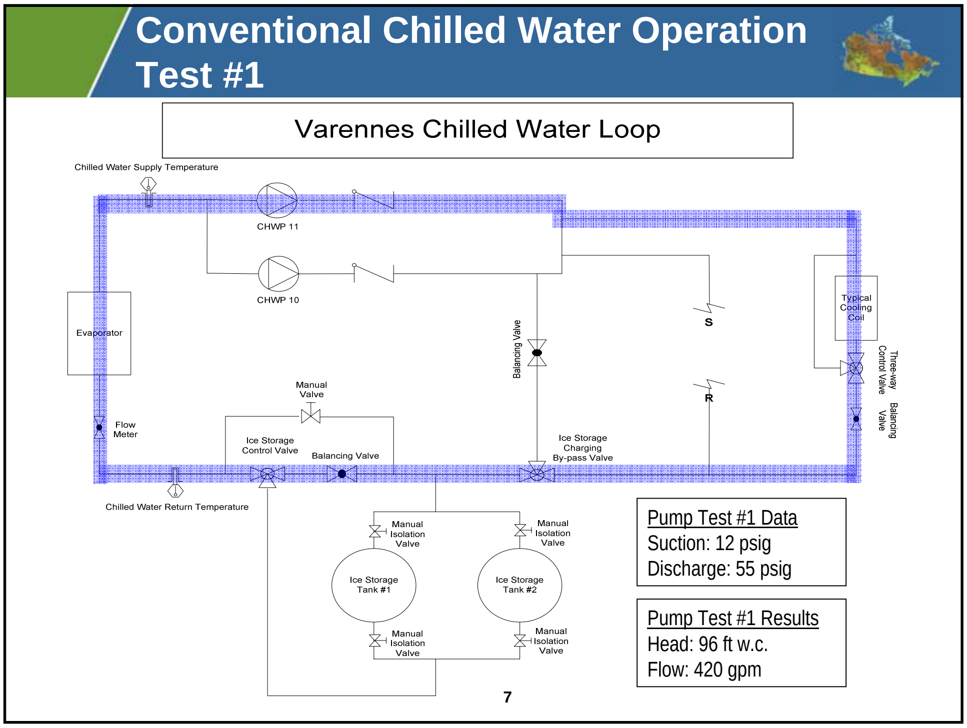
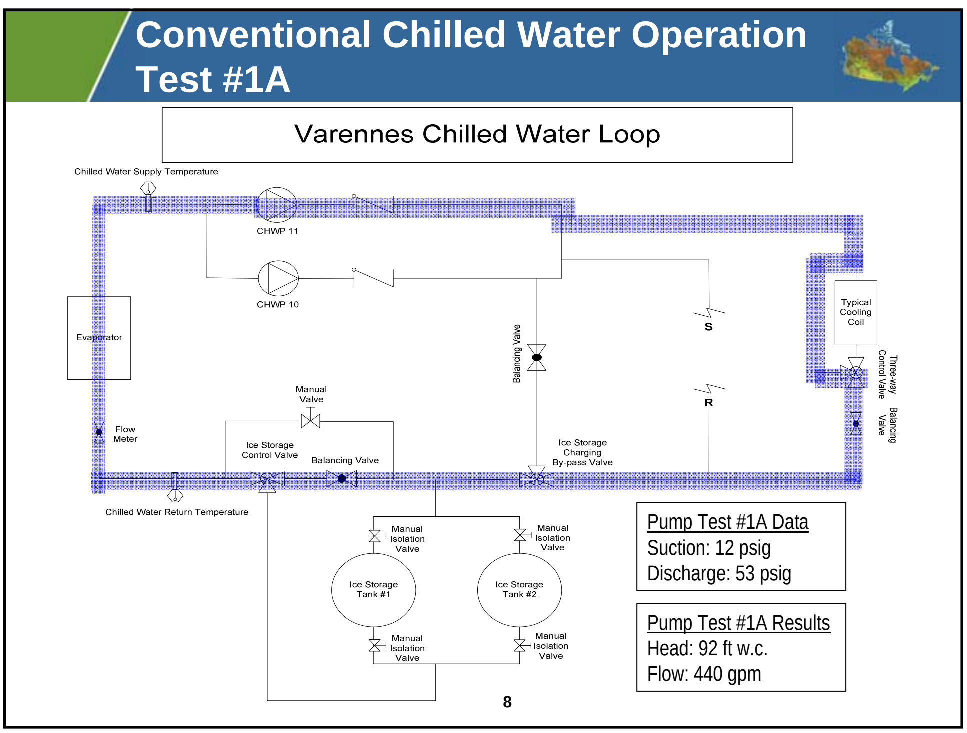

Conventional Chilled Water Operation Test #1
Varennes Chilled Water Loop
Chilled Water Supply Temperature
CHWP 11
CHWP 10
Evaporator
Balancing Valve
S
Typical Cooling Coil
Three-way Control Valve
Balancing Valve
R
Manual Valve
Flow Meter
Ice Storage Control Valve
Balancing Valve
Ice Storage Charging By-pass Valve
Chilled Water Return Temperature
Manual Isolation Valve
Ice Storage Tank #1
Ice Storage Tank #2
Pump Test #1 Data
Suction: 12 psig
Discharge: 55 psig
Pump Test #1 Results
Head: 96 ft w.c.
Flow: 420 gpm
7


Conventional Chilled Water Operation Test #1A
Varennes Chilled Water Loop
Chilled Water Supply Temperature
CHWP 11
CHWP 10
Evaporator
Balancing Valve
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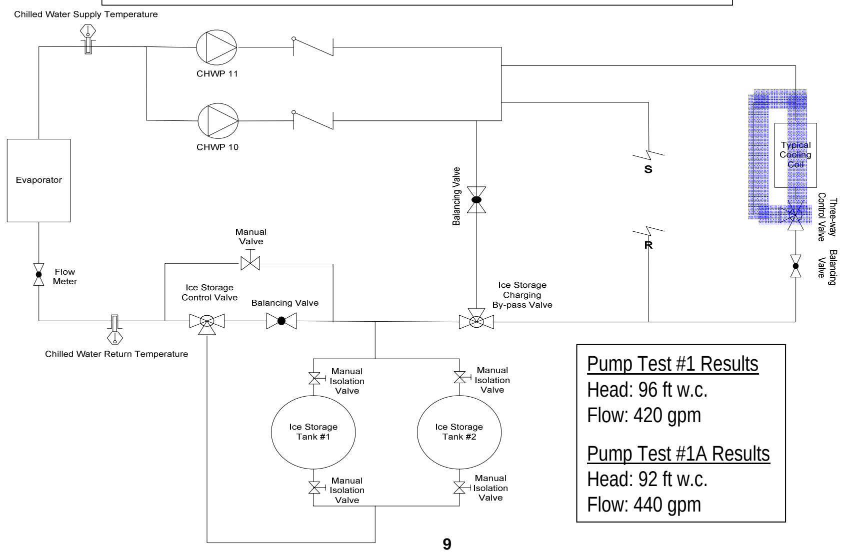
Typical Cooling Coil
Three-way Control Valve
Balancing Valve
R
Manual Valve
Flow Meter
Ice Storage Control Valve
Balancing Valve
Ice Storage Charging By-pass Valve
Chilled Water Return Temperature
Manual Isolation Valve
Ice Storage Tank #1
Ice Storage Tank #2
Pump Test #1A Data
Suction: 12 psig
Discharge: 53 psig
Pump Test #1A Results
Head: 92 ft w.c.
Flow: 440 gpm
8

Conventional Chilled Water Operation Test #1A

Varennes Chilled Water Loop



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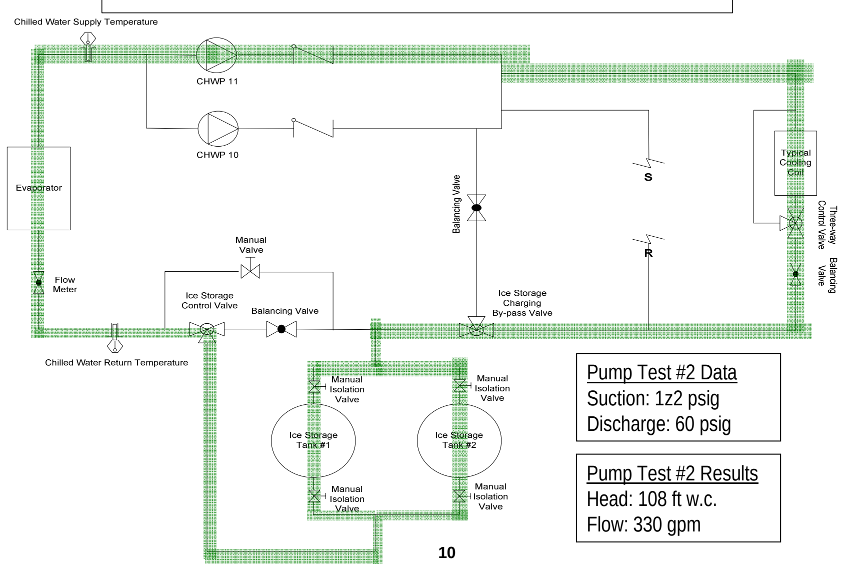
Ice Storage System Operation Test #2

Varennes Chilled Water Loop



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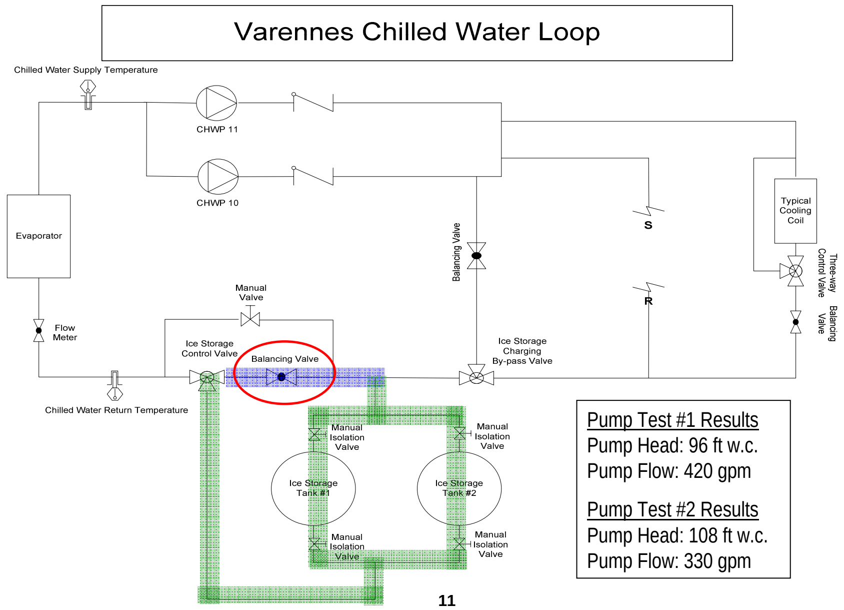
Ice Storage vs. Chilled Water



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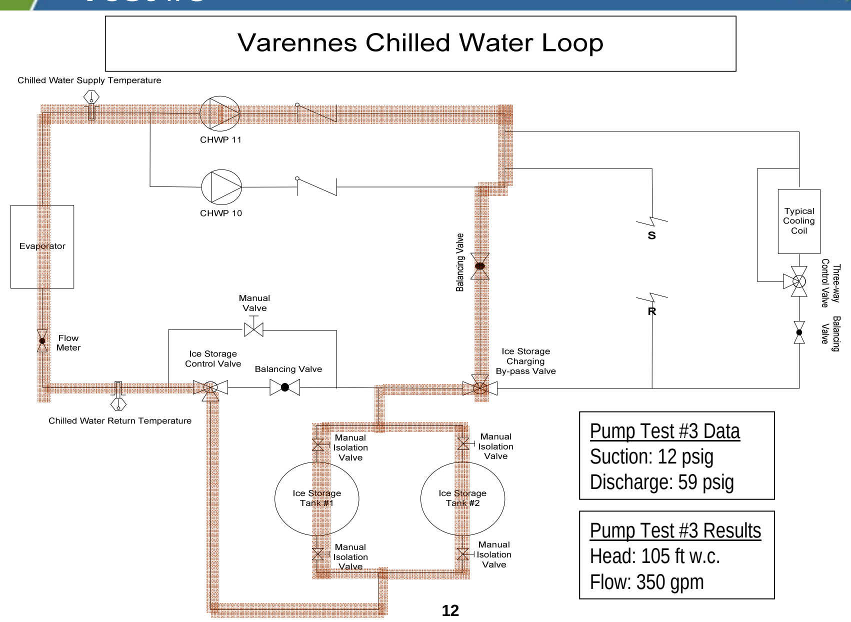
Charging the Ice Storage Tanks Test #3



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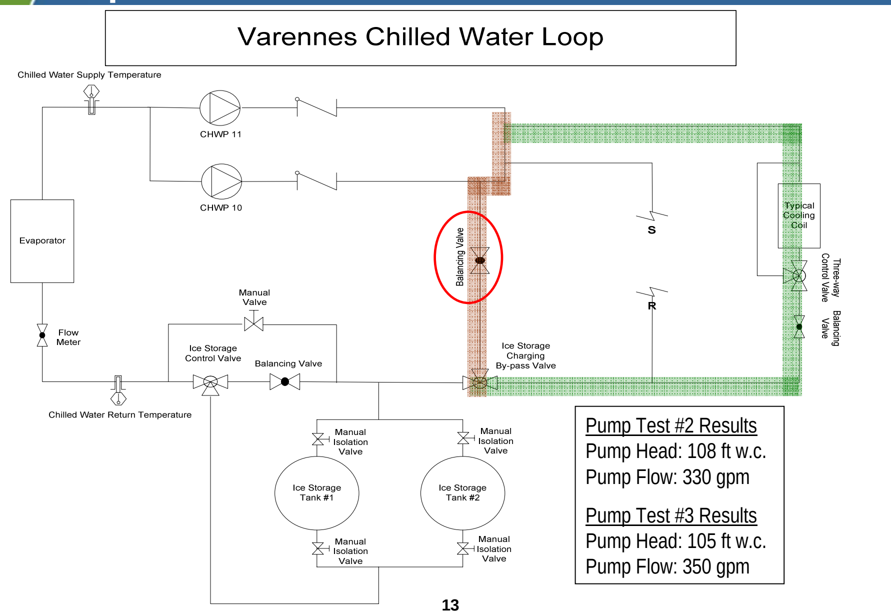
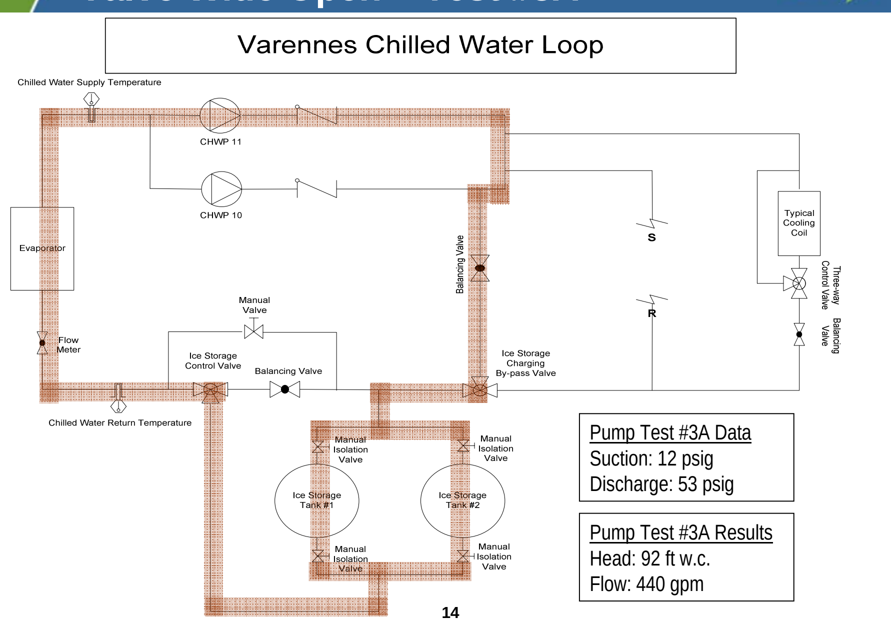
Ice Storage Charging By-pass Operation

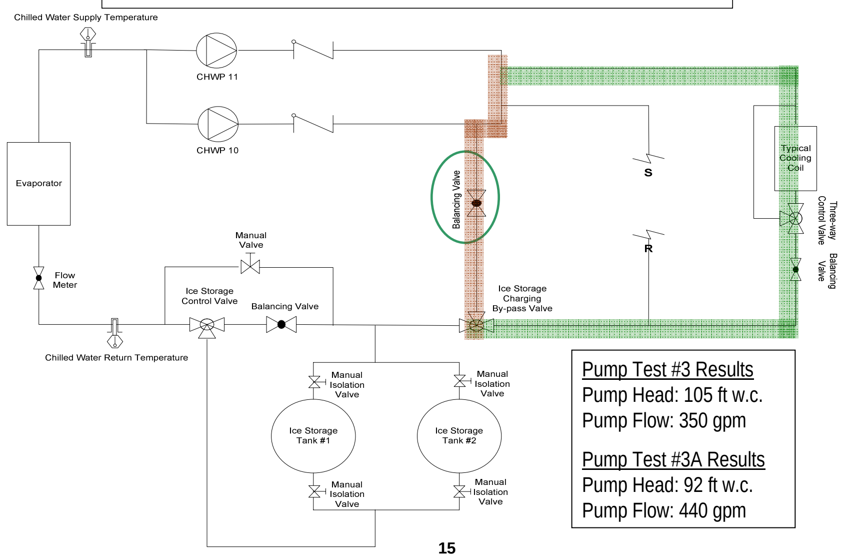


Ice Storage Charging Balance Valve Wide Open – Test #3A



Ice Storage Charging Balance Valve Wide Open

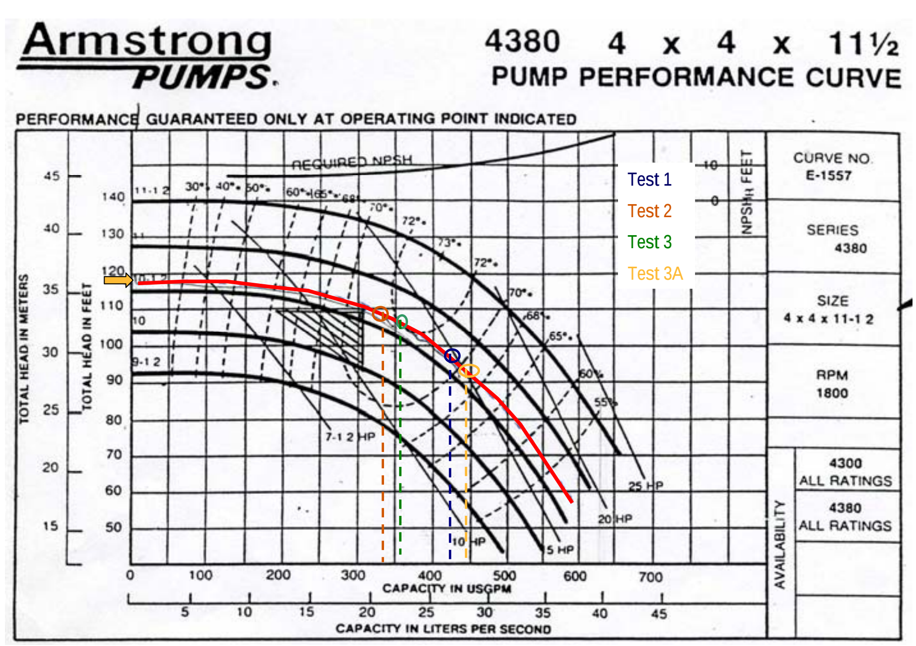
Varennes Chilled Water Loop



Pump Test #3 Results
Pump Head: 105 ft w.c.
Pump Flow: 350 gpm

Pump Test #3A Results
Pump Head: 92 ft w.c.
Pump Flow: 440 gpm

15



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Potential Savings

Advanced RCx Course

- Close ice storage control valve and balancing valve then throttle system back to achieve design flow rate
  - Operate closer to 12 HP rather than 15 HP
- Install VFD on chilled water pump
  - Open all balancing valves
  - Determine pump speed necessary to maintain design flow rate under all operating conditions
  - Reprogram the DDC system to accommodate new sequence of operations

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Part 2: Pumping System Analysis

Advanced RCx Course

- The second part of the hands-on activities will be to use data from a past project to fully evaluate the savings potential associated with a pumping system
- The objective of the hands-on activities is to apply the fundamentals discussed this morning to evaluate potential energy savings associated with trimming a pump impeller
  - Each team will calculate system pressure losses based on provided system diagram, equipment description, and test data
  - As a class we will develop total system head requirements
  - Then each team will work together on the pump performance analysis and calculate potential energy savings
  - Each team will present their findings and then we will discuss the findings as a class

SEE ACTIVITY SHEETS:
Review System Diagram and Pump Test Analysis (2 sheets)

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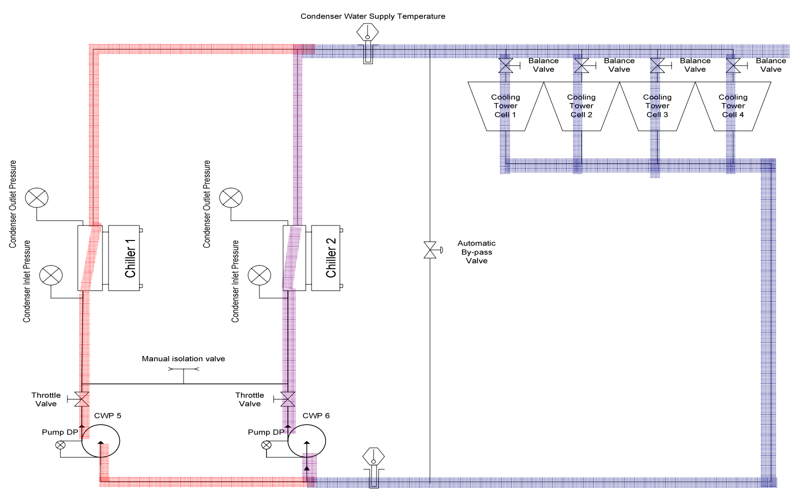
Pumping Example – System Data

- System description
  - Dedicated condenser water pumps to CH1 and CH2
  - 25 HP each
  - Throttling valves about 70% open
  - Design operating point is 990 gpm at 74 ft. head
  - Nameplate impeller diameter is 9.2 inch
  - Condenser water distributed across all cooling towers when any chiller is operating

Pumping Example – System Diagram

Condenser Water System Diagram



SEE ACTIVITY SHEET:
Condenser Water System Diagram

System Pressure Drop

Advanced RCx Course

- Group 1: CDP5 system pressure losses
- Group 2: CDP6 system pressure losses
- Group 3: Common piping pressure losses
- Special component pressure losses
  - Tower elevation: 10 ft
  - Triple duty valves: 2 psi pressure drop full open
  - Victaulic strainer: 1 psi pressure drop (clean)
  - Condenser bundle: 21 ft

SEE ACTIVITY SHEETS:
– Pipe Friction Chart (1 sheet)
– Equivalent Length of New Straight Pipe for Valves and Fittings (1 sheet)

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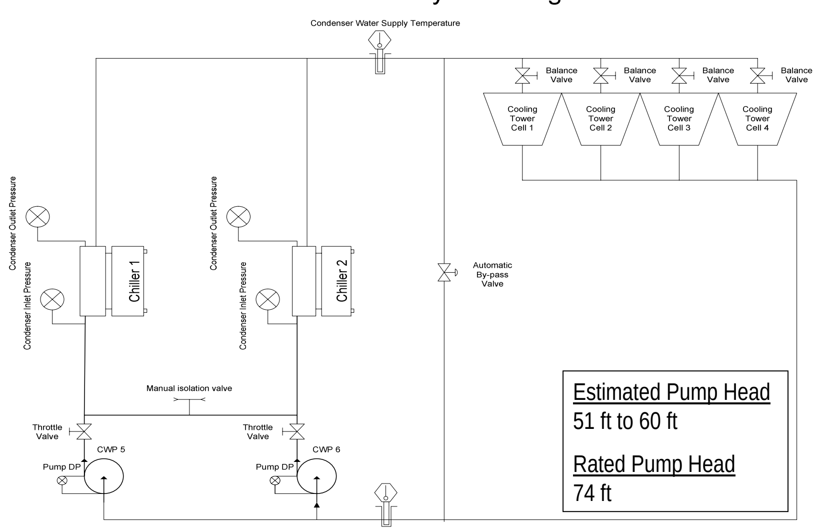
Pump Nameplate Data vs. Head Assessment

Condenser Water System Diagram



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Pumping Example – System Data

Advanced RCx Course

- Pump test results
  - No flow differential pressure: 80 ft
  - As-found differential pressure: 70 ft
  - Wide open differential pressure: 53 ft
- Plant operation
  - Lead chiller operates 3000 hr/yr
  - Lag chiller operates 1000 hr/yr

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Pumping Example – System Analysis

Advanced RCx Course

- Each group will use the test data and pump curve to:
  - Sketch installed impeller curve
  - Locate each operating point on the impeller curve (design; as-found, wide open)
  - Develop as-found and wide-open system curves
  - Determine proposed operating point and calculate energy savings
    - ➢Minimum savings associated with throttling to design
    - ➢Maximum savings associated with impeller trim

SEE ACTIVITY SHEETS:
–Evaluate Savings Associated with a Pumping System (3 sheets)
–Sulzer Paco – LC – 50957 – 1750 RPM – Performance Curve (1 sheet)

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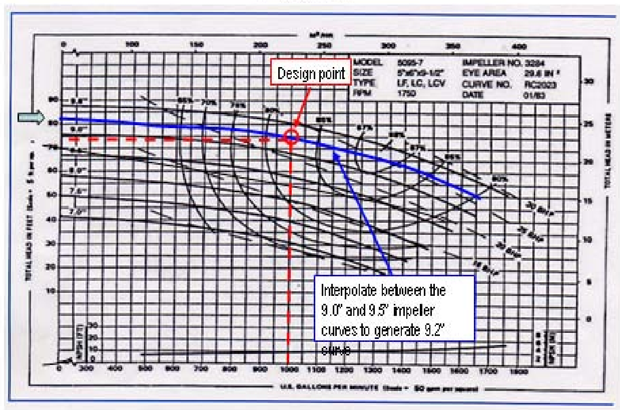
CDP/CDP6 Design Point

Advanced RCx Course



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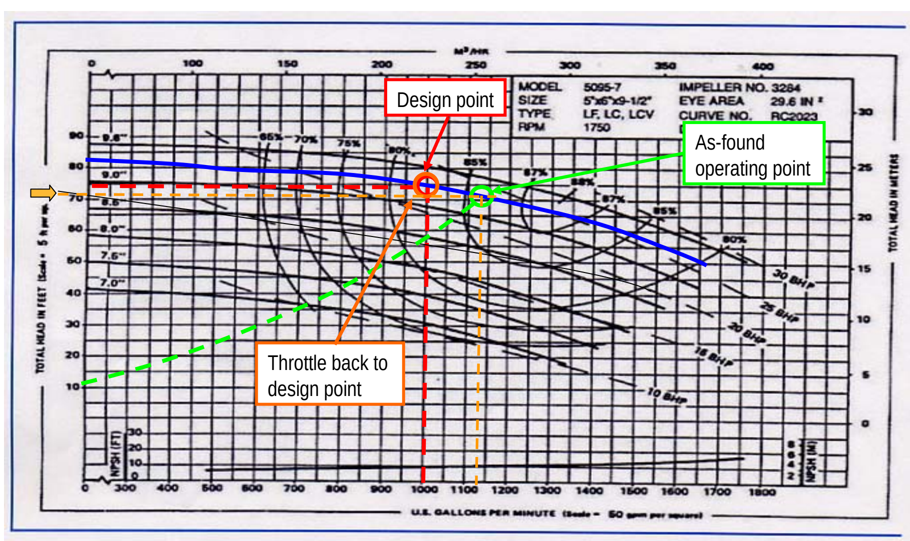
CDP 5/CDP 6 As-found Operating Point



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Pump Power Estimates

- As-found condition power

BHPaf = (1140 gpm x 70 ft w.c.) / (3960 x 86%)
= 23.4 hp

kWaf = (23.4 BHP / 90%) x 0.746 kW/hp
= 19.4 kW

- Minimum savings potential *(throttle back to design flow)*

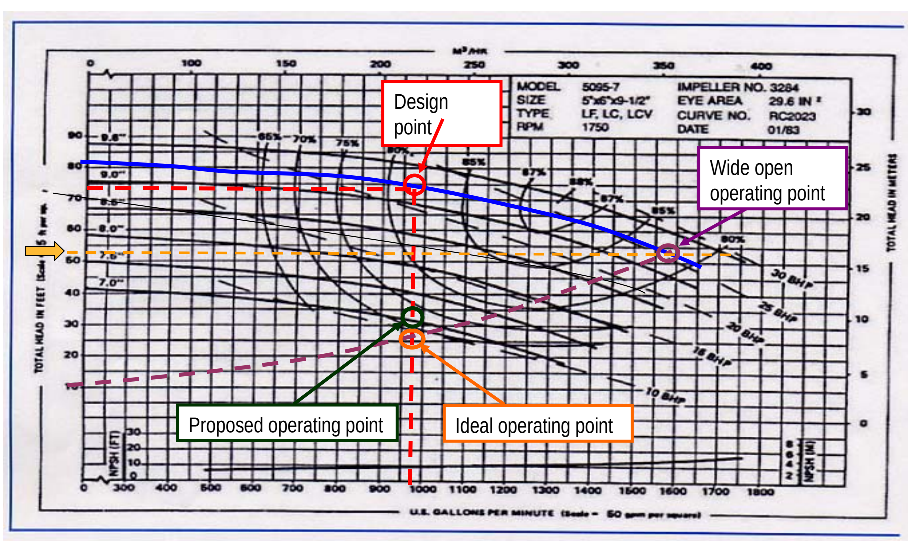
BHPmin = (990 gpm x 74 ft w.c.) / (3960 x 82%)
= 22.6 hp

kWmin = (22.6 BHP / 90%) x 0.746 kW/hp
= 18.7 kW

- Minimum power reduction

kWmin = 0.7 kW (4% reduction)

CDP 5/CDP 6 Wide Open Operating Point



Pump Power Estimates

Advanced RCx Course

- Maximum power savings (trim to 7 inch impeller diameter)

BHP_{max} = (990 gpm x 33 ft w.c.) / (3960 x 70%)
= 11.8 hp

kW_{max} = (11.8 BHP / 90%) x 0.746 kW/hp
= 9.8 kW

- Maximum power reduction

kW_{max} = 9.6 kW (50% reduction)

Potential Energy Savings

Advanced RCx Course

- Lead chiller operates 3000 hr/yr
- Lag chiller operates about 1000 hr/yr
- Minimum Energy Savings (ES)

ES_{min} = (0.7 kW x 3000 hr/yr) + (0.7 kW x 1000 hr/yr)
= 2,800 kWh/yr
= $235/yr (@$0.084/kWh average)

- Maximum Potential Energy Savings (ES)

ES_{max} = (9.6 kW x 3000 hr/yr) + (9.6 kW x 1000 hr/yr)
= 38,400 kWh/yr
= $3,220/yr (@$0.084/kWh average)

Implementation Cost

Advanced RCx Course

- **Option 1 – Throttle pump back to design flow**
  - No cost but very minimal cost savings
- **Option 2 - Trimming the existing impeller**
  - Contractor costs typically include tear down, trimming, reassembly with new gasket (new bearings and seals not included)
  - Seen price quotes between $500 and $1200 per pump
- **Option 3 – Buy new impeller**
  - New impeller can be upwards of $2500
  - Installed cost may be upwards of $3000 per pump
- **Payback (PB) Range**
  - Best case scenario (Option 2 – trim impeller)
    - **PB = within 4 months [($500 x 2) / $3220/yr]**
  - Worst case scenario (Option 3 – new impeller)
    - **PB = < 2 years [($3000 x 2) / $3220/yr]**

Resume

Advanced RCx Course

- What was learned?
  - Value of developing a system diagram
  - How to test a pump
  - How all of this culminates into an overall pumping opportunity evaluation

Building Operation Optimization

Advanced Recommissioning (RCx) Course

Phase 2: Investigation
(List of findings)

Developed by Portland Energy Conservation, Inc.

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Adapted by Natural Resources Canada's CanmetENERGY

www.canmetenergy.nrcan.gc.ca

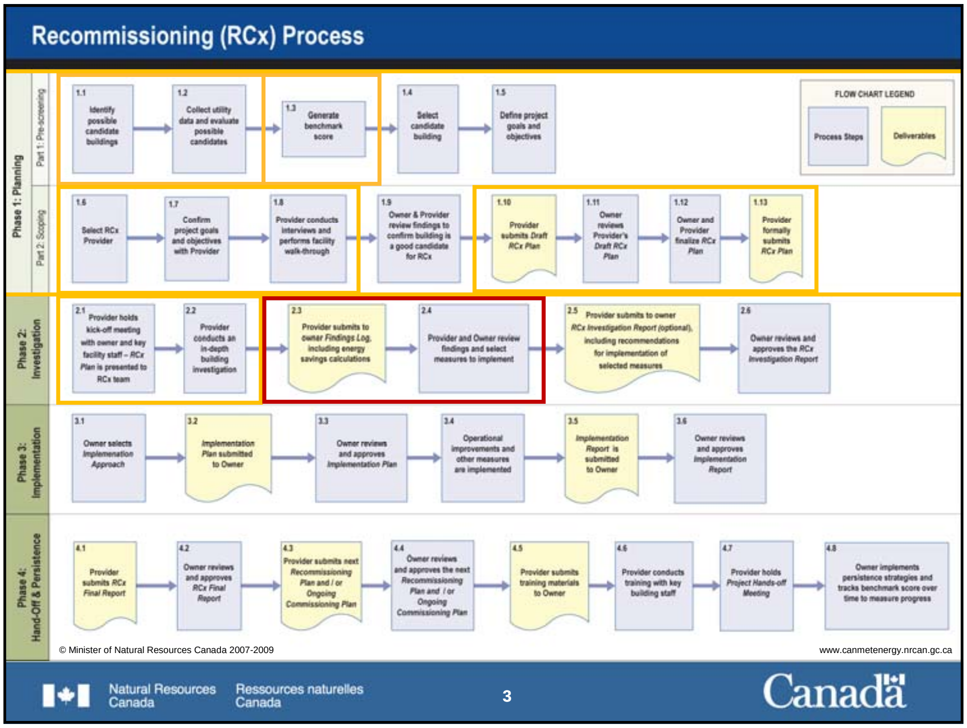
Preview

- **Where have we been?**
  - Planning phase
  - Investigation phase
- **What will we be doing now?**
  - Continue investigation with more examples of common RCx findings

ACTIVITIES:

Develop recommendation and estimate of savings for common RCx measures: schedule, setpoints, resets, economizers, ventilation control

Discuss how to get measures implemented



Investigation Phase

Advanced RCx Course

- List of findings
  - Common RCx Measures
  - Schedule
  - Setpoints
  - Resets
  - Economizers
  - Ventilation control

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Common RCx Findings

- Schedules
  - Equipment and lighting controls
- Improper setpoints
- Reset Control Issues
  - Incompatible setpoints
  - Common interactions
  - Chilled and condenser water reset
- Economizer Issues
- Ventilation control

Schedules – Overview

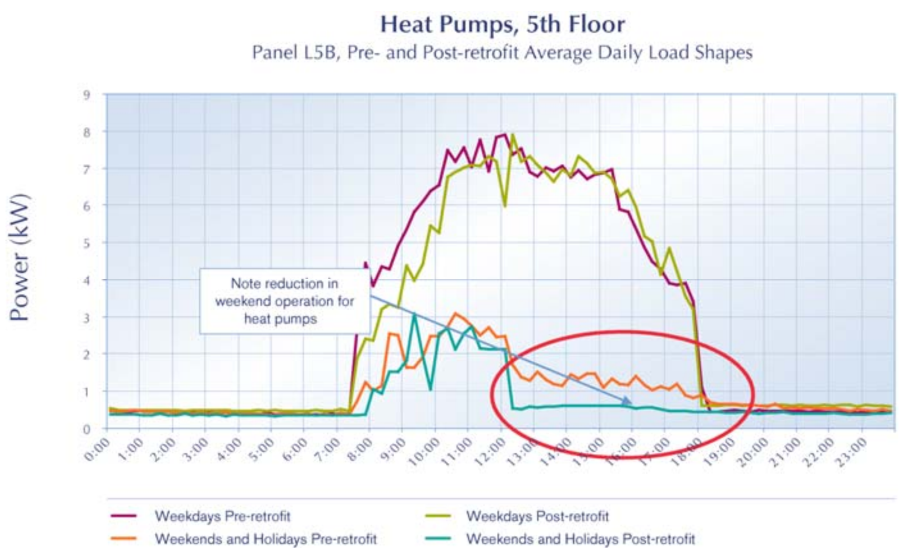
- Scheduling Issues
  - Schedules are often modified to accommodate specific, short-term occupant needs
  - Schedule modifications can be forgotten
  - Improper system installation can lead to occupant request for modified schedule
- How to identify
  - Trend data can be used to identify system operation
  - Interval utility data can be used to indicate a scheduling problem
  - After hours walk-through if possible

Schedules
Example #1 – Heat Pumps

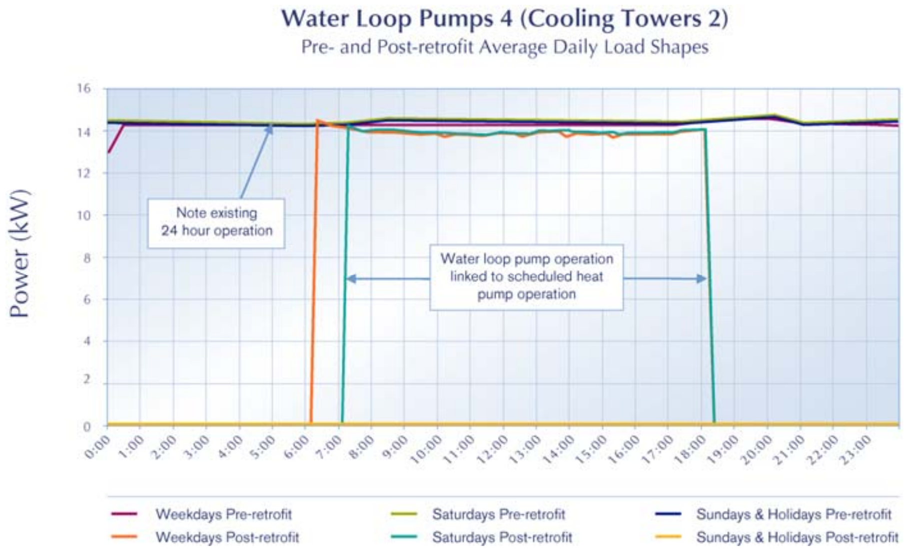
Advanced RCx Course

- As-found situation
  - Heat pump schedules were modified to accommodate short-term occupant requests
  - Heat pumps were commanded on when building unoccupied
  - Water loop circulation pumps ran continuously (no schedule)
  - Fluid cooler spray pump and fan ran while building unoccupied
- Identified during investigation via system trends and data loggers on the equipment

Improved Heat Pump Scheduling



Improved Water Loop Pump Operation



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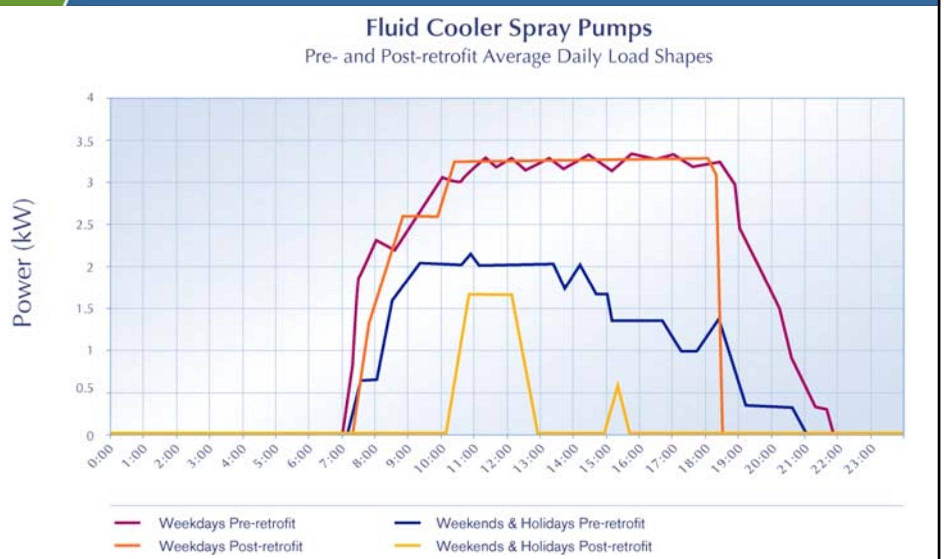
Improved Spray Pump Schedules



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Schedules
Example #1 – Heat Pumps

Advanced RCx Course

- System description
  - West loop and East loop circulation pumps were 20 HP and 15 HP, respectively
  - Two fluid coolers each with 20 HP fan and 3 HP spray pump
  - 175 heat pumps ranging from 1 ton to 3 ton capacity
  - Only 50% heat pumps should have a Saturday schedule

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Schedule

Schedules
Example #1 – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Schedule

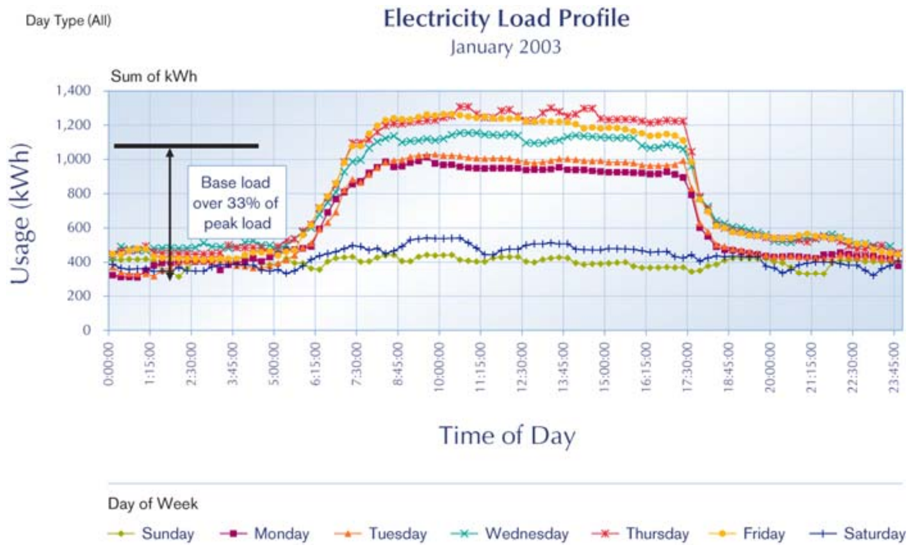
Schedules
Example #1 – Past Project

- Savings opportunity
  - Estimate energy savings: ≈ 219,000 kWh/yr
  - Estimated annual cost savings: ≈ $17,000
- Owner action
  - Heat pump schedules were modified to reflect actual need of the building and BAS reprogrammed so that the loop pumps only operate when heat pumps are scheduled to be “enabled”
  - Actual implementation cost: $243
  - Simple payback: immediate
- Post-retrofit verification
  - System operation verified via trends and data loggers
  - Utility interval data also confirmed reduction in weekend and unoccupied hour operation

Schedules
Example #2 – Lighting Controls

- As-found situation
  - Occupants did not have access override switches located in locked closet
  - Zone names programmed into the system were unrecognizable by facility operating staff
  - Too few relays on some floors created zoning problems
  - Lighting sweep control system was disabled and majority of lights are on 24/7
- Identification of a problem came from evaluation of 15-minute utility interval data and system trend data

Schedules
Example #2 – Lighting Controls



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Schedules
Example #2 – Lighting Controls

Advanced RCx Course

- System description
  - Current unoccupied hours: 4056 hr/yr
  - About 110 kW of lighting on 3rd thru 7th floors
  - About 30% lights on emergency circuit (still operate 24/7)
  - Estimated occupant override: 480 hr/yr (40 hr/month)

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Schedules
Example #2 – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

Schedules
Example #2 – Past Project

Advanced RCx Course

- Savings opportunity
  - Estimate energy savings: 349,000 kWh/yr
  - Estimated annual cost savings: $14,000
- Owner action
  - Lighting circuits being mapped and given appropriate zone names
  - Additional relays are being added to improve zoning
  - Override switches are being moved
- Primary barrier to implementation
  - Occupants need to be trained on how the system will operate and how to turn lights back on for after hours operation

Schedules – Summary

Advanced RCx Course

- Not glamorous, but still the best way to save energy
  - Schedules are often modified to accommodate specific, short-term occupant needs
  - Schedule modifications can be forgotten
  - Improper system installation can lead to occupant request for modified schedule
- Effective ways to identify opportunities
  - Trend data
  - Interval utility data
  - After hours walk-through if possible

Improper Setpoints – Overview

Advanced RCx Course

- Setpoint Issues
  - Design setpoint values may not be appropriate when operating at less-than-design conditions
  - Setpoints may not be clearly specified in the design
  - Setpoints are often changed from design values to address comfort complaints
- How to identify
  - Variable volume systems may act more like a constant volume system
  - High base utility loads during swing and summer months may indicate operational issues like excess reheat
  - Trend data can be effective at identifying operational problems

Variable Air Volume (VAV) Box Flow Setpoints

Advanced RCx Course

- Design load conditions often look at worst case situations
  - Seldom seen in real world day to day operation. Actual people and equipment loads are typically lower
  - Space usage may have changed and original design conditions are no longer valid
- Clues to help identify issues
  - Cold comfort complaints in zones that do not have reheat
  - In our particular example, boilers firing on a 50% duty cycle during month of July and no process loads
  - Low CO_2 measurements with the zone
  - Trends
    - VAV box damper position
    - VAV box minimum flow setpoint
    - Measured VAV box minimum flow
    - Reheat valve position
    - Electric reheat status/command (if applicable)
    - Supply fan VFD command/feedback

VAV Box Flow Setpoints

Advanced RCx Course

- Things to consider
  - Keep flow above minimum velocity pressure necessary for flow ring to measure accurately
  - Electric reheat minimum flow requirements
  - If using CO_2 to check ventilation, ensure system is not in economizer mode (over ventilation may be due to free cooling)
  - Consider simply reducing minimum flow setpoint gradually and observing system operation.
  - “Canned” sequences may limit ability to change settings
  - Keep in mind minimum turn-down capability of the air handling system
  - Probably don’t want to go to zero minimum

Setpoints
Example #1 – VAV Box Flow

Advanced RCx Course

- Differences between the design and actual conditions

Item	Design	Actual	Comment
Number of people	2	1	Two chairs, 1 for a visitor
Length	10 ft.	10 ft.	
Width	12 ft.	12 ft.	
Lighting Level	1 w/sq. ft.	1 w/sq. ft.	
Computer name plate amps	6 amps	6 amps	Average .5 amps per reading
Monitor name plate amps	2 amps	2 amps	Average 1.5 amps per reading
AHU minimum outdoor air percentage from ASHRAE multispace equation	30%	30%	

Item	Cooling Load		Ventilation Load	
	Design	Actual	Design	Actual
People	147 W (500 Btu/hr)	73 W (250 Btu/hr)	18.9 L/s (40 cfm)	9.5 L/s (20 cfm)
Lights	120 W (410 Btu/hr)	120 W (410 Btu/hr)	N/A	N/A
Computer	961 W (3,276 Btu/hr)	240 W (819 Btu/hr)	N/A	N/A
TOTAL	**1,228 W (4,186 Btu/hr)**	**433 W (1,479 Btu/hr)**	18.9 L/s (40 cfm)	9.5 L/s (20 cfm)

Setpoints
Example #1 – VAV Box Flow

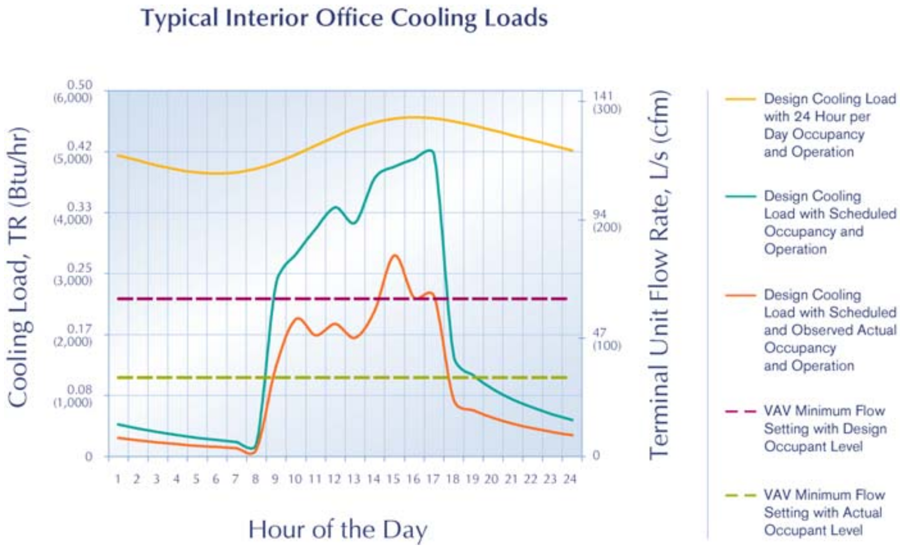
Advanced RCx Course

- Different load requirements = Different flow requirements
  - Flow required to meet the actual load is below the design minimum flow setting

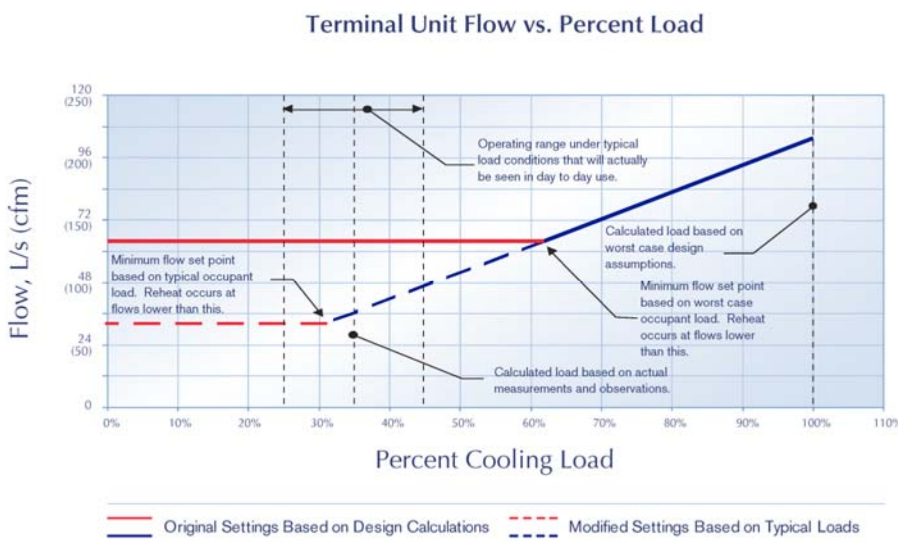
Item	Design	Actual
Cooling load	(4,186 Btu/hr) 0.35 TR	(1,479 Btu/hr) 0.12 TR
Units conversion constant	1.08	1.08
Space temperature	(75°F) 23.9°C	(75°F) 23.9°C
Supply temperature	(57°F) 13.9°C	(57°F) 13.9°C
Flow required	(215 cfm) 101.5 L/s	(76 cfm) 35.9 L/s
Minimum flow setting	(133 cfm) 62.8 L/s	(67 cfm) 31.6 L/s

- About a 40% reduction in minimum flow rate!

Setpoints
Example #1 – VAV Box Flow



Setpoints
Example #1 – VAV Box Flow



Setpoints
Example #1 – VAV Box Flow

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- Reverse engineering 800,000 ft^2 (74,322 m^2) complex reveals ventilation set for 6,000 people with actual census of 1,850
  - Numerous conference rooms
  - Occupants generally from surrounding offices (minimal transient occupancy)
  - Average occupancy ratio of 30%
  - Generally in use 50% of the time

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Setpoints

Setpoints
Example #1 – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Setpoints

Setpoints
Example #1 – Past Project

Advanced RCx Course

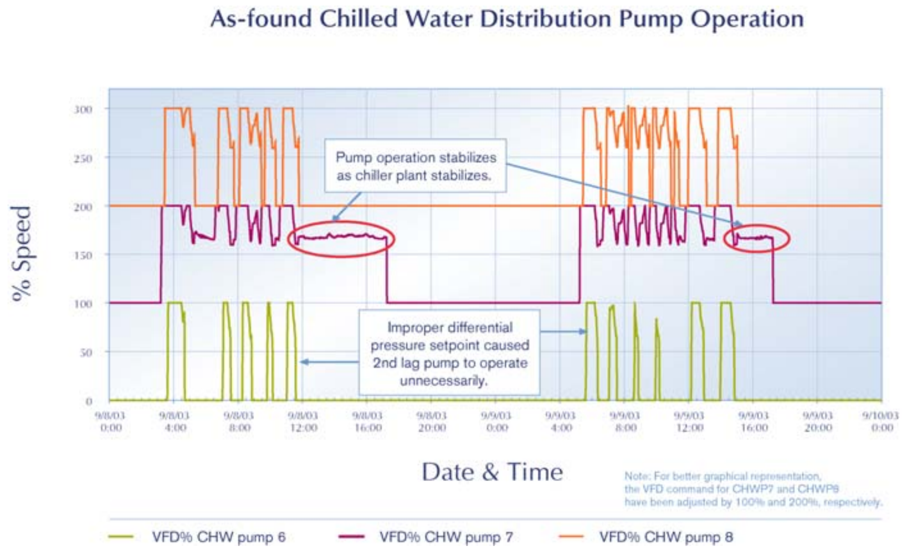
- Savings opportunity
  - $10,000 for investigation, programming changes, and verification saved $30,000 per year at $0.04/kWh
    Note: savings included some scheduling of VAV boxes as well
- Owner action
  - Lower VAV box minimum flow setpoint as applicable
  - Monitor system performance

Setpoints
Example #2 – Pump Pressure

Advanced RCx Course

- VFDs on secondary chilled water pumps are controlled to maintain pressure setpoint across the pumps
- Control sequences state that the differential pressure setpoint is to be reset based on pressure at remote sensor. However, a remote pressure setpoint is not specified.
- The remote sensor measures differential pressure between supply and return lines at the furthest cooling coil (AHU1)
- Based on piping losses, valve pressure requirements, and cooling coil design pressure drop, system head loss is estimated at approximately 20 ft.wg.
- As-found differential pressure setpoint was 35 ft.wg.

Setpoints
Example #2 – Pump Pressure



Setpoints
Example #2 – Pump Pressure

- System description
  - Three, 40 HP secondary pumps controlled by VFDs
  - Cooling operating hours: 1300 hr/yr total plant
  - As-found conditions included the 2nd lag pump cycling on and off (average of 40%) and operating near 95% speed
  - After adjusting setpoint, the 2nd lag pump turned off completely and other pump VFDs backed off

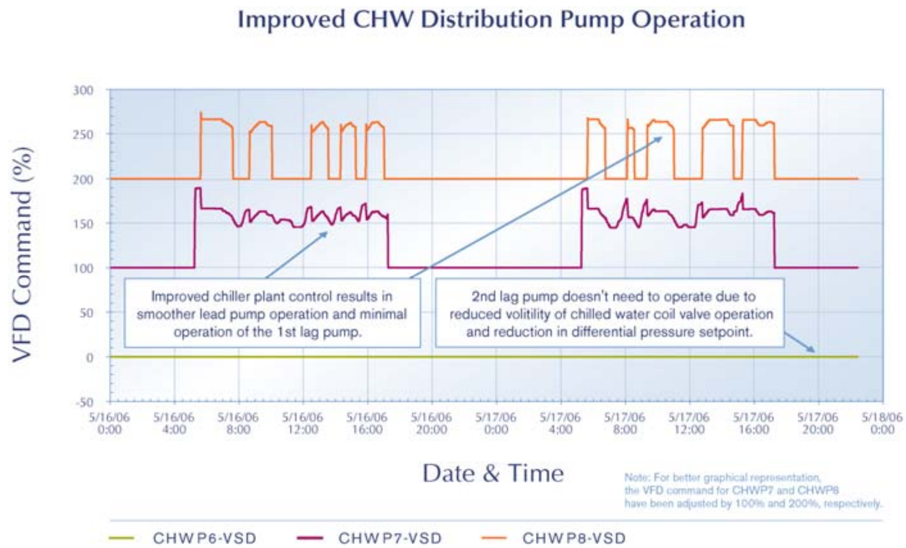
Setpoints
Example #2 – Activity Sheet

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

Setpoints
Example #2 – Past Project

- Savings opportunity
  - Estimate energy savings: ~25,000 kWh/yr
  - Estimated annual cost savings: ~$2,000
  - Implementation: time to determine setpoint value and adjust programming

Setpoints
Example #2 – Pump Pressure



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Improper Setpoints – Summary

Advanced RCx Course

- Setpoint Issues
  - Design setpoint values may not be appropriate when operating at less-than-design conditions
  - Setpoints may not be clearly specified in the design
  - Setpoints are often changed from design values to address comfort complaints
- Effective ways to identify opportunities
  - Things just don't make sense based on observed conditions
  - High base utility loads during swing and summer months
  - Trend data

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Reset Control Interactions – Overview

- Reset Control Issues
  - Multiple reset strategies can be incompatible and counteract
  - Resetting minimum or maximum setpoints by facility operators in response to comfort complaints can cause operational problems
  - Selecting which reset strategies to execute at any given time may depend on operating conditions and energy savings potential
- How to identify
  - Variable volume systems may act more like a constant volume system
  - Things just don't make sense based on observed conditions
  - Control instability for various systems
  - Trend data can be effective at identifying operational problems

Reset

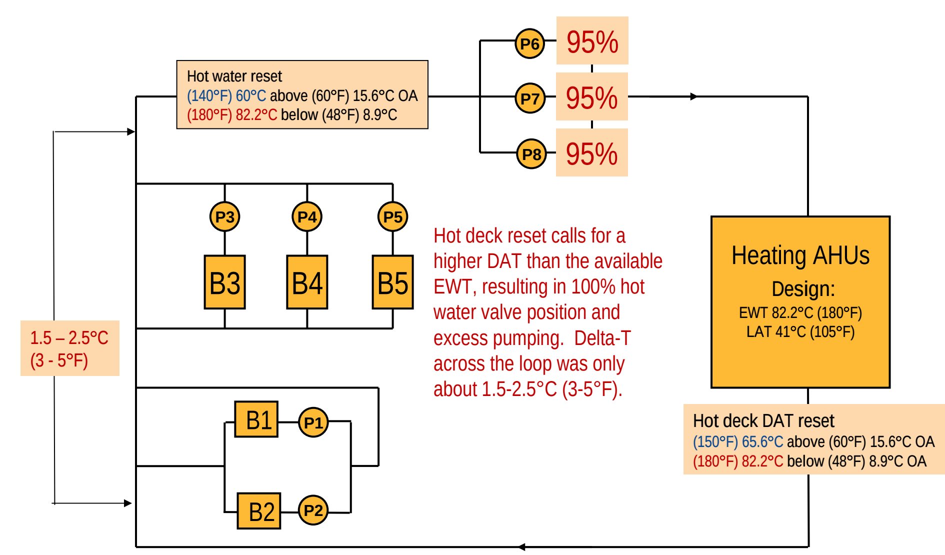
Example #1 – Air Handling Unit (AHU) DAT Setpoint

- Building walk-thru in late spring, all three secondary distribution pumps operating at 100% speed
- Low delta-T in the secondary hot water loop
- Trend data was used to monitor system operation and verify individual control strategies
  - Discharged Air Temperature (DAT) setpoint and measured values
  - Heating water (HW) setpoint and measured values
  - Hot water coil valve positions
  - Variable frequency drive (VFD) pressure setpoint, measured value, and speed feedback
  - Secondary loop flow rate and supply/return temperatures

Reset
Example #1 – AHU DAT Setpoint

- Hot-deck AHU discharge air temperature reset issues
  - DAT minimum setpoint was higher than hot water minimum temperature setpoint
  - DAT maximum setpoint was same value as hot water maximum temperature setpoint
  - DAT maximum setpoint was higher than coil design at maximum entering water temperature

Reset
Example #1 – AHU DAT Setpoint



Reset
Example #1 – AHU DAT Setpoint

Advanced RCx Course

- System description
  - Two, 100,000 cfm hot-deck air handling units controlled by VFDs
  - Three, 15 HP secondary distribution pumps controlled by VFDs
  - Two, 865 MBH condensing boilers with 1/2 HP pumps and three, 2800 MBH non-condensing boilers with 1-1/2 HP pumps

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Resets

Reset
Example #1 – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

SEE ACTIVITY SHEET

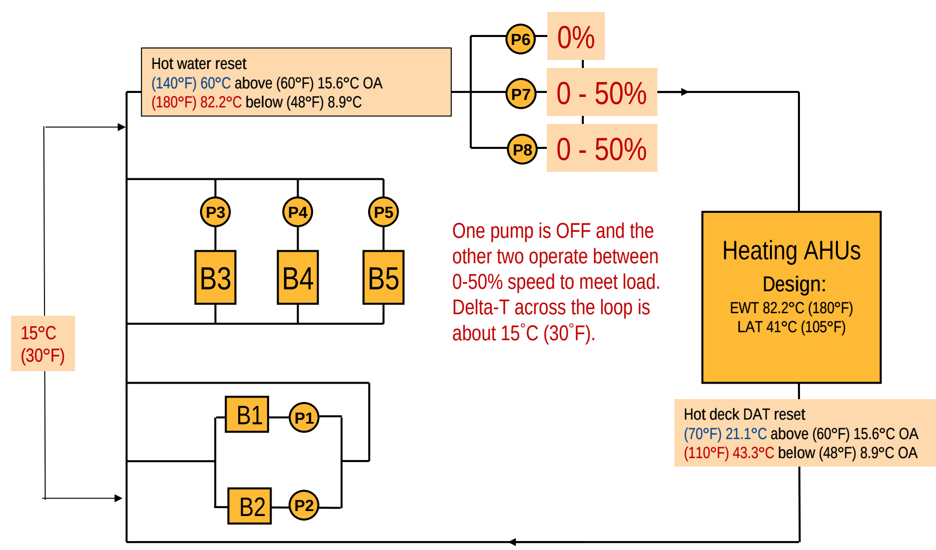
List of findings (Common RCx Measure) - Resets

Reset
Example #1 – Past Project

Advanced RCx Course

- Savings opportunity
  - Estimate energy savings: 26,000 kWh/yr and 123 MWh/yr (4,200 therm/yr)
  - Estimated annual cost savings: $4,800 total
- Action Taken
  - DAT reset values were adjusted at the operator work station
  - Implementation: time to determine optimum setpoint value and adjust programming

Reset
Example #1 – AHU DAT Setpoint



Follow-up Issue

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- Remaining hot-deck AHU DAT reset issues
  - Warm-up cycle has hard wired discharge air temperature setpoint (i.e. is not linked to DAT reset schedule). During warm-up cycle, DAT setpoint is 82.2°C (180°F), which cannot be achieved and the hot water plant starts to run wild.
  - Identified and verified by trend analysis

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Typical AHU Reset Examples

Advanced RCx Course

- Common supply static pressure reset parameters
  - VAV box damper position (feedback from damper)
  - Zone cooling demand (cooling loop PID output)
- Common discharge air temperature reset parameters
  - Outdoor air temperature
  - VAV box damper position
  - Deviation from zone temperature setpoint (reset loop may need to execute faster than zone temperature loop to reset DAT first, then modulate damper and reheat valve to meet zone setpoints)
  - Zone cooling demand

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Typical AHU Reset Examples

Advanced RCx Course

- Zone cooling demand
  - A more effective reset control strategy is to adjust discharge air temperature based on the actual cooling demand for the respective zones being polled, as determined by the zone temperature control loop output signal. The control strategy is best described by the following example.

Assume a single zone temperature loop output ranges between 0 and 200, with the output range of 0 to 100 modulating the reheat valve from full open to fully closed (at minimum air flow) and the output range of 100 to 200 modulating the primary air damper from minimum to maximum cooling air flow. The discharge air temperature reset control loop would start to lower the air temperature incrementally towards the air temperature low limit in order to maintain the polled zone temperature loop output value at 125 as zone loads increased. Then, as zone loads decrease, raise the discharge air temperature setpoint incrementally towards the air temperature high limit in order to maintain the zone temperature loop output value at around 75.

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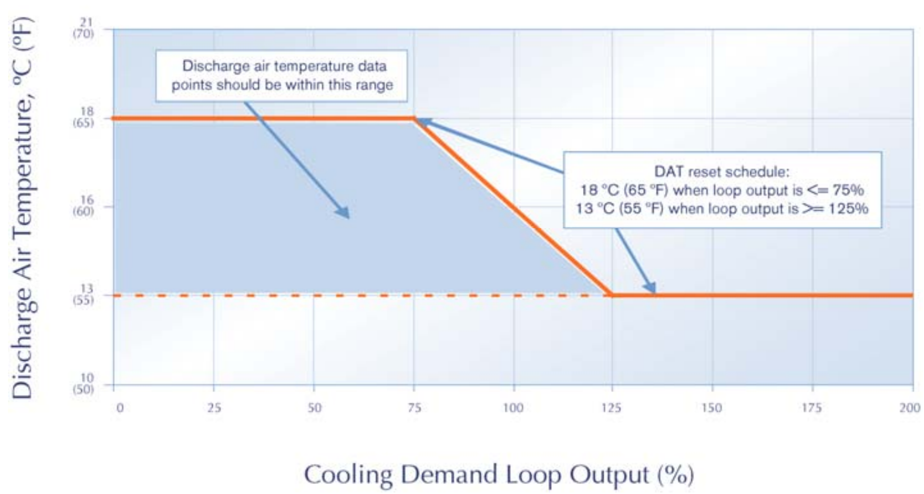
Zone Load Demand



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AHU Reset Interactions

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- Raising the discharge air temperature setpoint will tend to cause a VAV box damper to modulate open because warmer air is trying to satisfy the loads within the zone served. This in turn will cause the static pressure setpoint to be raised, increasing fan energy VAV box damper position (feedback from damper)
- If both reset strategies are based on the same parameter, for example VAV box damper position, the discharge air temperature setpoint would decrease and the duct static pressure would increase at the same time (depending on how frequently each control loop is executed). As a result, more air flow at much lower temperature will be delivered, potentially overcooling the space. This would cause the damper to modulate closed, and the reset strategies would then cause the temperature and pressure setpoints to swing in the other direction.

Minimize Negative Interactions

Advanced RCx Course

- Use different reset parameters
- Adjust control loop execution speeds
- To optimize system operation, evaluate which control strategy will generate the best reduction in energy use under different atmospheric conditions or building loads and modify control sequences as necessary.
- For example, the heating, cooling, and reheat benefits associated with resetting discharge air temperature may far outweigh increased supply fan energy usage during winter and swing seasons, whereas static pressure reset may be optimal during warmer atmospheric conditions.

Additional Reset Examples

- Chilled water reset
  - Reset chilled water temperature (CHWT) higher as loads decrease
  - Typical savings about 1% per 1°C (2°F) CHWT delta T° increase
- Condenser water reset
  - Reset condenser water temperature (CWT) based on outdoor air conditions
  - Typical savings about 0.5% per 1°C (2°F) CWT delta T° decrease

Optimizing Tower Fan Energy

- Cooling towers working hard to make 22°C (72°F) water
  - Theory; Lower condensing temperature = Lower chiller kW/ton
  - But achieving a fixed setpoint at all ambient conditions is unrealistic
  - Outdoor air at (85°F) 29°C db/50% RH yields about (71°F) 22°C wet bulb temperature
  - Tower approach is (6°F) 3°C
  - Lowest possible water temperature is (77°F) 25°C
- Incrementally raising the setpoint to (80°F) 27°C:
  - Raised the chiller by 14 kW
  - Dropped out two 20 hp (39 kW total) continuously running tower fans
  - Reduced consumption by $18,000 - $20,000 annually
  - Based on $.07/kWh electricity

Photo Credit:
Portland Energy Conversation, Inc. (PECI)

Reset Control Interactions – Summary

Advanced RCx Course

- Reset Control Issues
  - Multiple reset strategies can be incompatible and counteract
  - Resetting minimum or maximum setpoints by facility operators in response to comfort complaints can cause operational problems
  - Selecting which reset strategies to execute at any given time may depend on operating conditions and energy savings potential
- Effective ways to identify opportunities
  - Things just don't make sense based on observed conditions
  - Control instability for various systems
  - Trend data can be effective at identifying operational problems
  - A lot of regular complaints

Economizer Control - Overview

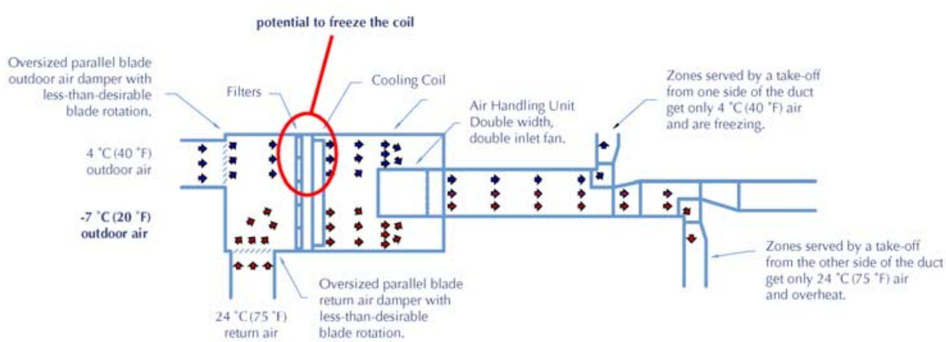
Advanced RCx Course

- Control Issues
  - Poor mixing and control
    - ➢ Installation geometry
    - ➢ Outdoor conditions
    - ➢ System turn-down
  - Change-over
    - ➢ Triggering condition
    - ➢ Set point
- How to identify
  - Trends
  - Operational problems (like frequent freezestat trips during start-up in cold weather)
  - System observations

Mixing Performance Dependencies

- Damper should have been sized for a linear characteristic
  - Velocity and pressure drop related
    - Impacts air flow through damper
  - Velocity also:
    - Provides momentum for air stream penetration
    - Promotes turbulence
- Linkage should also be arranged to promote linearity
  - Identical for OA and Return sections
  - Kinematics promote linear relationship between stroke and blade rotation
- Damper blade rotation directs air streams to promote mixing
- Sufficient distance to mix
- Good sensing input for control

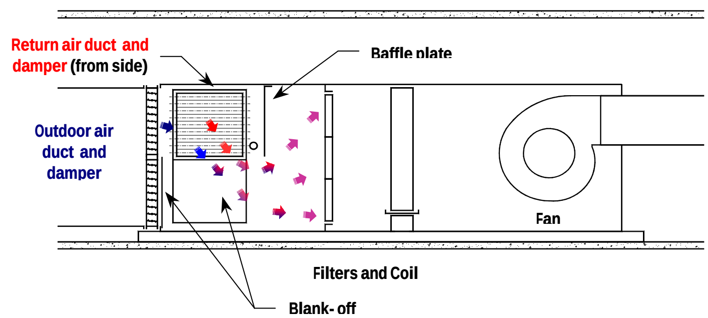
Strange Things Can Happen



Fixing Poor Mixing with Baffle Plates and Damper Modifications

Advanced RCx Course

- Field solution for existing poor mixing problem
  - Disable damper blades to increase velocity
    - Better flow vs. stroke characteristic
    - More momentum
  - Add baffle plates to deflect air flow



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Fixing Poor Mixing with Air Blenders

Advanced RCx Course

- Field solution to an existing problem
- Planned solution to a design problem

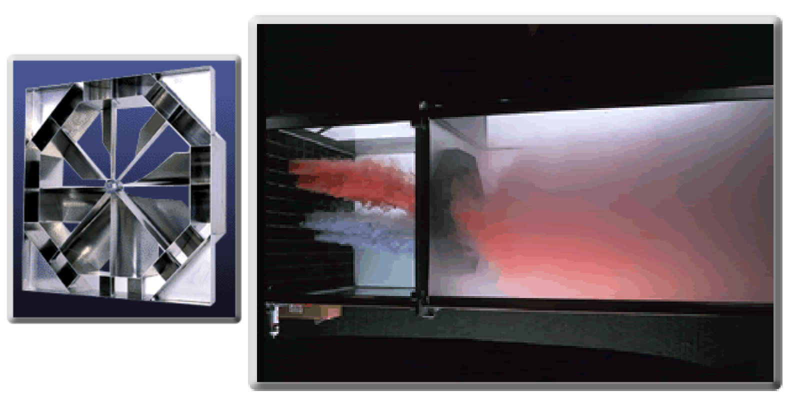

Photo Credit: Blender Products

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Damper Sizing Impacts Economizer Performance

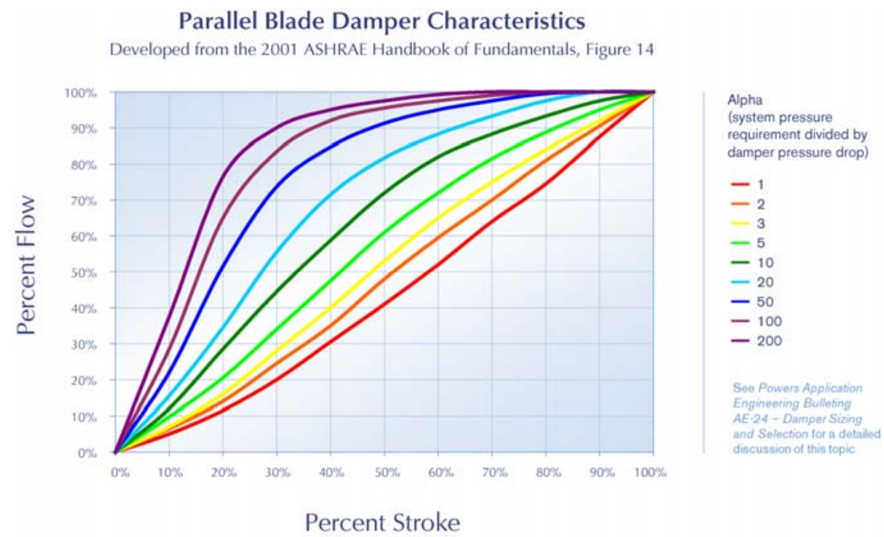
- VAV systems that perform well at design can fail to perform at low flow rates
  - System turn-down creates the same effects as poorly sized damper sections
  - System turn-down can aggravate sensing problems
- Flow variations can change the mixed air plenum pressure relative to ambient
  - Plenum to OA pressure difference drives outdoor air flow
  - System flow variations may produce minimum outdoor air flow variations

Control Performance Dependencies

- Damper should have been sized for a linear characteristic
  - Dampers need to have a significant percentage of the system pressure drop taken across them in order to be effective in controlling flow
- Rule of thumb – velocities less than 8 m/s (1,500 fpm) across the damper assembly probably yields marginal damper linearity

$$\left(\frac{\text{Flow Rate in m}^3/s}{\text{Damper Area in m}^3}\right) = \text{Damper velocity in m/s}$$

Parallel Blade Damper Characteristics



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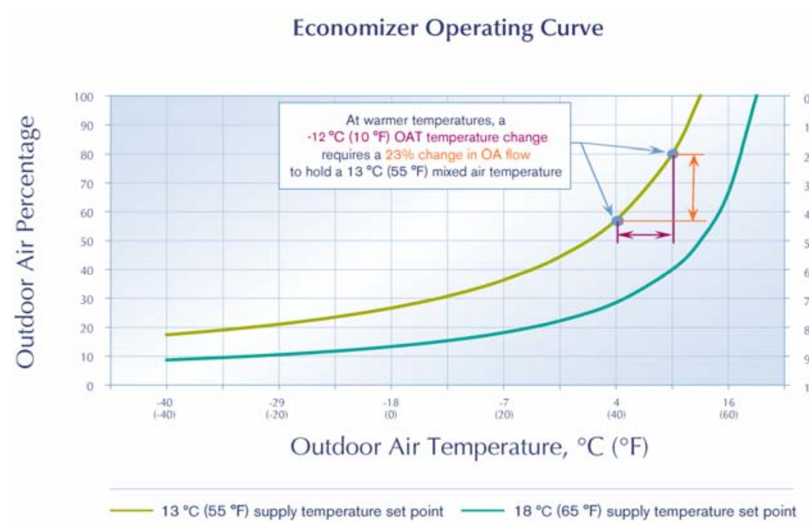
Economizer Control Process



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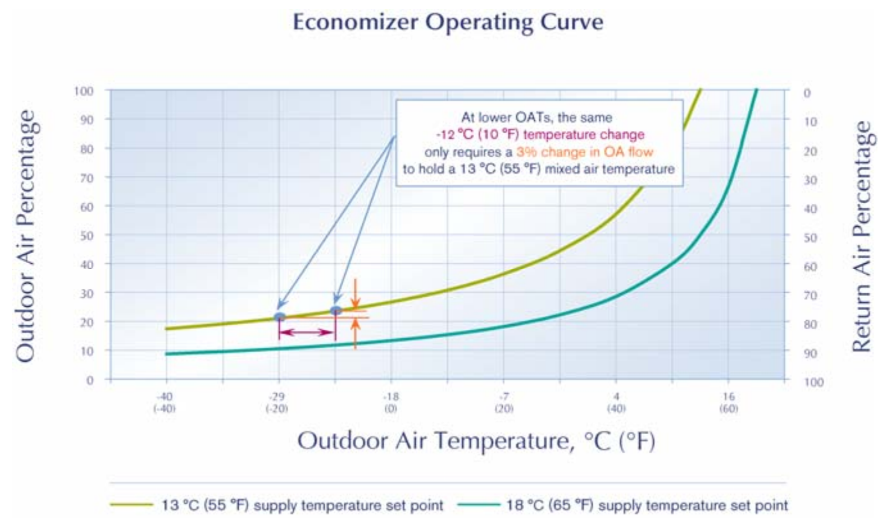
Economizer Control Process



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Control Performance Problems

Advanced RCx Course

- Economizer may bring in way more air than necessary if the damper assembly is oversized
  - Small change in damper position can result in large variation in air flow resulting in poor control
- Colder outdoor air temperatures can exacerbate control problems
  - Less cold outdoor air must be blended with return air to satisfy control setpoint, which requires tighter control over damper movement and air flow

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Economizer Change-Over Approaches

Advanced RCx Course

- Outdoor air dry-bulb temperature based
  - Doesn't take humidity into account
  - Right *MOST* of the time, but not *ALL* of the time, especially humid climates
  - Close dampers to minimum position when OAT>RAT with 2ºC threshold
- Enthalpy based
  - Singe point (change-over strategy)
    - Assumes space condition
    - Lower cost
  - Multi-point (differential strategy)
    - Measures space condition

Enthalpy Switches

Advanced RCx Course

- Respond to total heat content of the air
  - Sensible temperature
  - Humidity
- Adversely impacted by:
  - Water
  - Direct or reflected sunlight
- Need to see a free flowing stream of outdoor air
  - Not protecting them from water and sun can cause some problems with this
  - Conditions during off cycle can produce unanticipated operating modes at start-up

Example #1 Economizer Control Strategy

Advanced RCx Course

- Control issues
  - Differential enthalpy control strategy
  - Outdoor humidity not an issue at building location
  - Relative humidity sensors needed frequent calibration
  - Economizer was being disabled unnecessarily

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Economizers

Economizer Exemple #1 – Control Strategy (con't)

Advanced RCx Course

- System description
  - Two air handling units rated at 52,000 L/s (110,000 cfm) each
  - Two air handling units rated at 57,000 L/s (120,000 cfm) each
  - Economizer locked out when OAT greater than 19°C (67°F)
  - Average return temperature is 23°C (73°F)
  - Chilled water plant connected load: 1.1kW/ton (including chillers, pumps, cooling towers)
  - Bin hours > 22°C (72°F): 220 hours per year
  - Bin hours > 19°C (67°F): 340 hours per year

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Economizers

Economizer Example #1 – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) - Economizers

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Economizer Example #1 – Past Project

Advanced RCx Course

- Estimated load calculations
  - Utility rate of $0.05/kWh
- Estimated savings potential
  - Energy savings of about 61,750 kWh/yr
  - Cost savings of about $3,100/yr (@ $0.05/kWh)
  - Estimate implementation cost of $2,000 (includes investigation and programming changes)

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Economizer Control - Summary

Advanced RCx Course

- Control Issues
  - Poor mixing
    - Installation geometry
    - Outdoor conditions
    - System turn-down
  - Change-over
    - Triggering condition
    - Set point
- Effective ways to identify opportunities
  - Trends
  - Operational problems (like frequent freezestat trips during start-up in cold weather
  - System observations

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Ventilation Control – Overview

Advanced RCx Course

- Opportunities
  - Reduce ventilation air flow rate as occupancy loads within individual zones and the building decrease
  - Applicable to both constant and variable air volume HVAC systems
  - Minimum outdoor air is a function of varying and non-varying ventilation requirements
- How best to identify
  - Trend data on VAV box operation
  - CO_2 monitoring
  - High base load energy usage

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Ventilation Control – Concepts

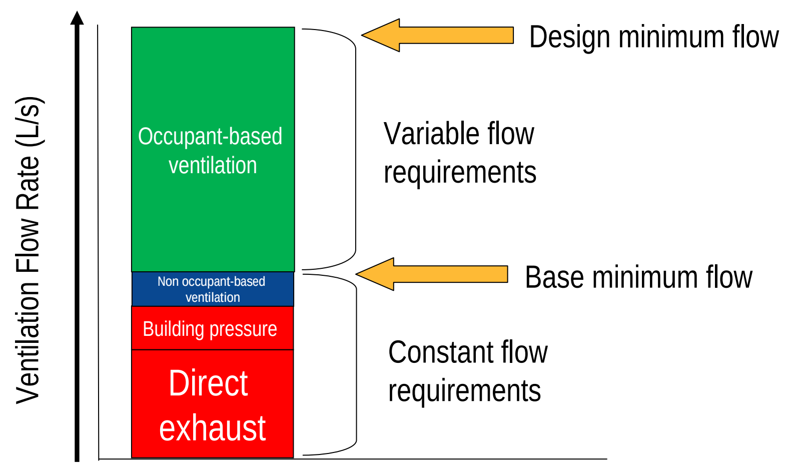
- Minimum outdoor air is a function of varying and non-varying ventilation requirements
  - Non-varying loads
    - Direct exhaust
    - Building pressurization
    - Non occupant-based ventilation requirements
  - Varying loads
    - Occupant-based requirements

Ventilation Control Opportunities

- Base Minimum ventilation requirements
  - Direct exhaust
  - Building pressure requirements
  - Non occupant-based requirements
- Design Minimum ventilation requirements
  - Base Minimum ventilation + occupant-based requirements
- Ventilation setpoint can be reset between Base Minimum and Design Minimum values

Ventilation Control Opportunities

Advanced RCx Course



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Demand Controlled Ventilation

Advanced RCx Course

- Carbon Dioxide often selected as indicator of occupancy levels
- Sensing technology becoming robust and cost effective, with reduced calibration requirements
- ASHRAE Guideline 62.1-2004 Appendix C outlines relationship between ventilation cfm per person and CO_2 level in parts per million (adequate indoor air quality for both varying and non-varying loads)
  - Typical background is 300-400 ppm
  - Control for 700-800 ppm above background with a cap at 1,100 ppm absolute measurement

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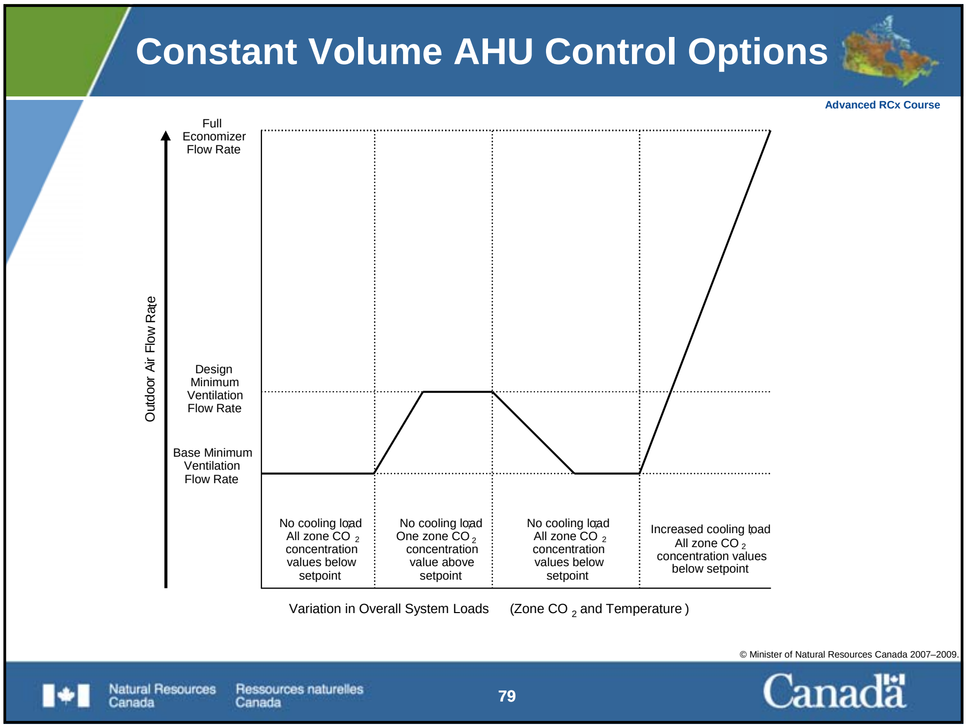
Things to Consider

- Sensor location
  - Return air stream
  - Critical zone
  - Outdoor air CO_2 sensor
- May lose control of a VAV box if minimum primary air flow rate is too low
- Minimum flow rate required to ensure adequate distribution from the diffuser
- Electric resistance heating element flow requirements
- Economizer control strategy takes precedence over DCV control strategy

Savings Potential

- Constant volume systems
  - Reduce heating and cooling load associated with ventilation air (chillers, boilers, pumps)
- Variable air volume systems
  - Reduce reheat at zone level
  - Reduce supply fan energy usage
  - Reduce heating and cooling load associated with ventilation air


Constant Volume AHU Control Options
Advanced RCx Course
Full Economizer Flow Rate
Outdoor Air Flow Rate
Design Minimum Ventilation Flow Rate
Base Minimum Ventilation Flow Rate
No cooling load All zone CO 2 concentration values below setpoint
No cooling load One zone CO 2 concentration value above setpoint
No cooling load All zone CO 2 concentration values below setpoint
Increased cooling load All zone CO 2 concentration values below setpoint
Variation in Overall System Loads (Zone CO 2 and Temperature)
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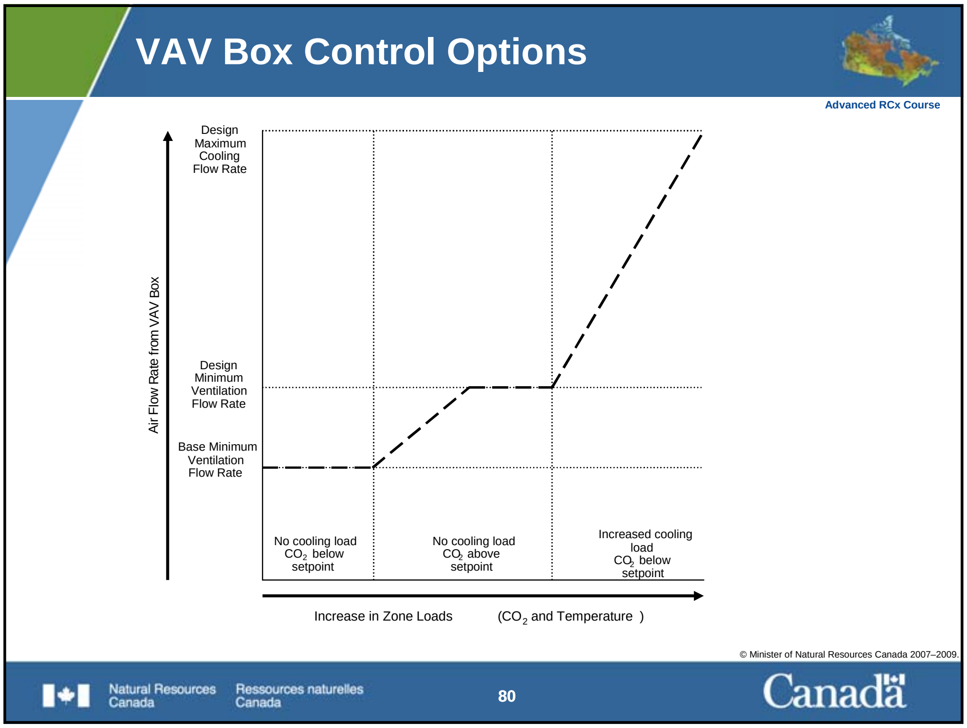
VAV Box Control Options
Advanced RCx Course
Design Maximum Cooling Flow Rate
Air Flow Rate from VAV Box
Design Minimum Ventilation Flow Rate
Base Minimum Ventilation Flow Rate
No cooling load CO2 below setpoint
No cooling load CO2 above setpoint
Increased cooling load CO2 below setpoint
Increase in Zone Loads (CO2 and Temperature)
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Combined OAD and VAV Box Control

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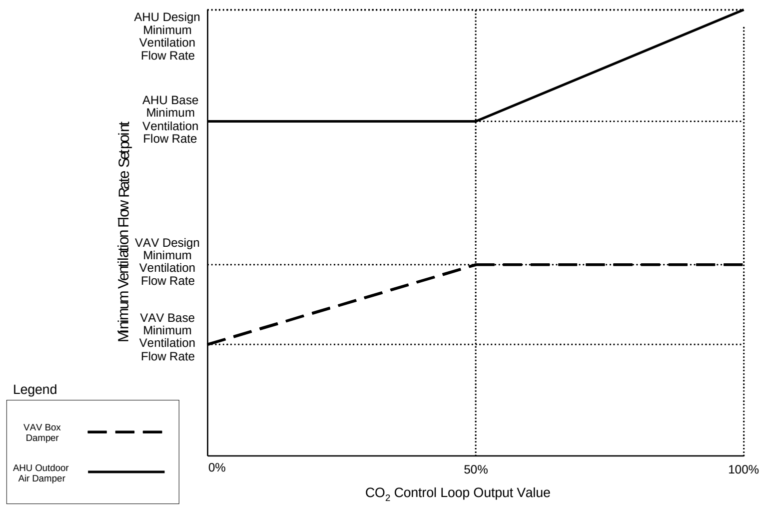

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Identifying DCV Opportunities

Advanced RCx Course

- Rough estimate
  - Estimate actual occupancy load and patterns
  - Multiply number of occupants by 7 to 10 L/s/person (15 to 20 cfm/person)
  - Compare estimated ventilation rate with current ventilation rate
- Use portable CO_2 device to take spot-check measurements or trend over time
  - If measuring CO_2, must correlate readings with economizer operation

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) – Ventillation Control

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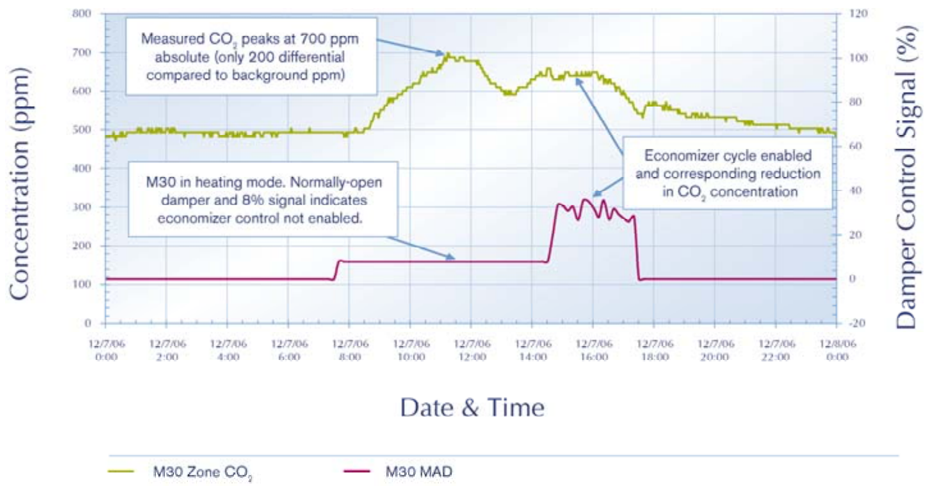
Measured CO_2 Concentrations Example: M30 Zone Data



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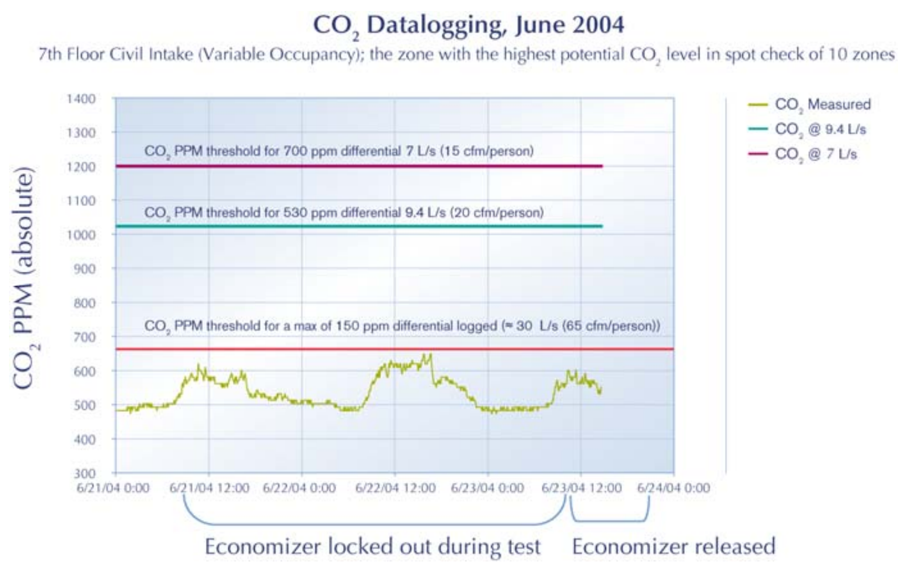
Measured Concentration Comparisons



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Ventilation Control – Activity Sheet

Advanced RCx Course

- Measure Description and Recommendation
  - What is the primary issue?
  - How would we resolve the problem?
- Estimate measure savings
  - What formula(s) should we use?
  - What information do we need?
- Estimate cost savings potential
  - Are there demand savings?
  - Are there energy savings?
  - Other savings potential?

SEE ACTIVITY SHEET

List of findings (Common RCx Measure) – Ventillation Control

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Ventilation Control – Summary

Advanced RCx Course

- Opportunities
  - Reduce ventilation air flow rate as occupancy loads within individual zones and the building decrease
  - Applicable to both constant and variable air volume HVAC systems
  - Save central plant energy (both CV and VAV systems) as well as supply fan energy (in VAV systems only)
  - Use VAV boxes in heat mode when possible, to avoid reheat

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Ventilation Control – Summary

Advanced RCx Course

- Effective ways to identify opportunities
  - Trend data on VAV box operation
    - ➢Damper positions
    - ➢Flow setpoint and measured flow
    - ➢Reheat valve positions
  - Trend central air handling unit
    - ➢Supply static pressure setpoint
    - ➢Measured supply static pressure
    - ➢OSA and Mixed air damper positions
    - ➢Supply fan VFD command
  - CO_2 monitoring
  - High base load energy usage

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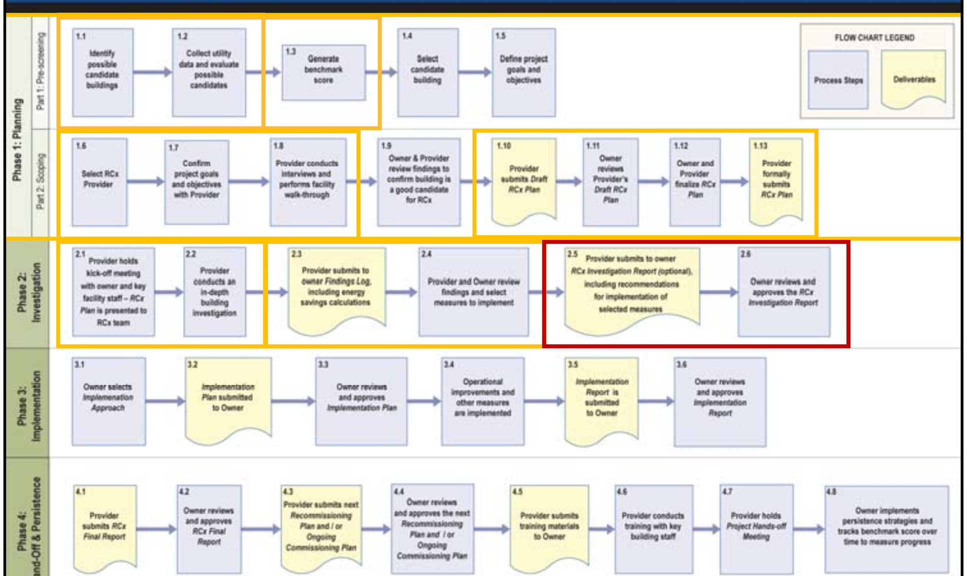
Recommissioning (RCx) Process



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Investigation Report (optional)

Advanced RCx Course

- When the findings log is not sufficient
- Includes detailed findings on
  - Site assessment
  - Building documentation review
  - Utility bill analysis
  - Diagnostic trending and testing

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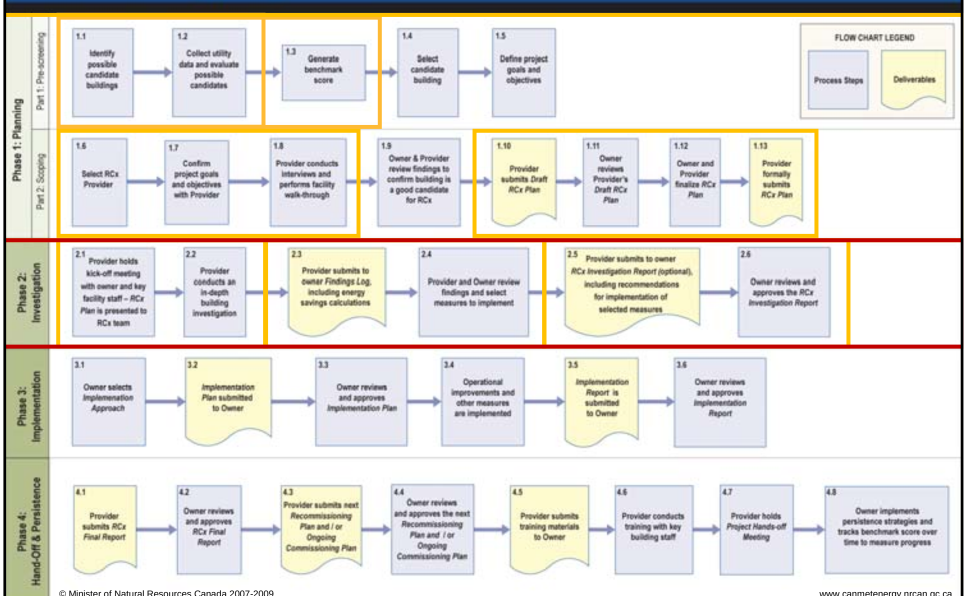
Recommissioning (RCx) Process



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Building Operation Optimization
Advanced Recommissioning (RCx) Course

Phase 3: Implementation

Developed by Portland Energy Conservation, Inc.

P | E | C | I

Adapted by Natural Resources Canada's CanmetENERGY

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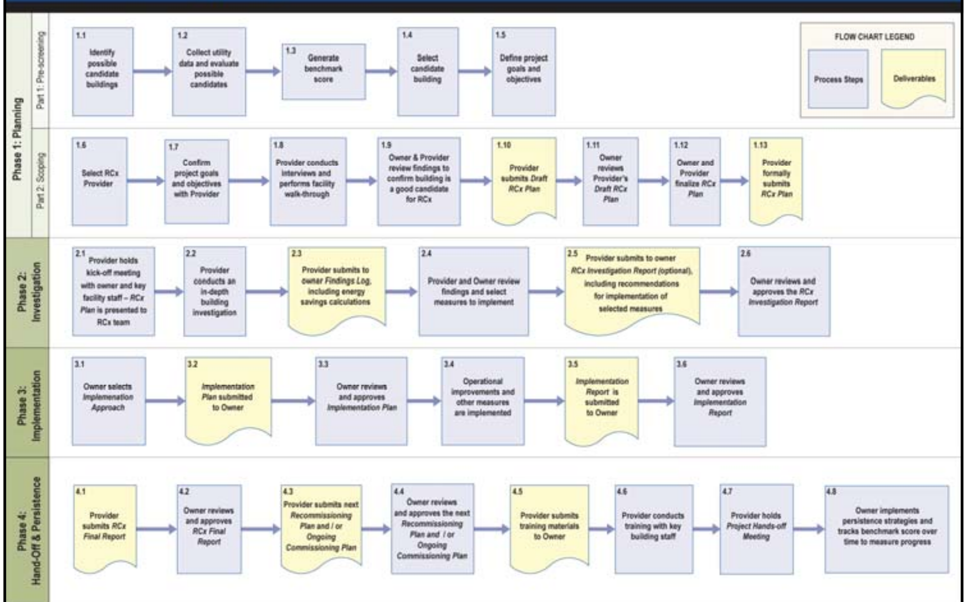
Recommissioning (RCx) Process



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RCx Implementation Phase

Advanced RCx Course

- Develop a detailed implementation plan, scopes of work for each measure, specs/acceptance criteria, and budget (more critical if work performed by outside contractor)
- Implement the cost-effective improvements selected by the owner
- Verify and document results (Implementation Summary)

SEE SAMPLE ISSUE LOG SUMMARY (2 SHEETS)

Implementation Approaches

Advanced RCx Course

- Turn-key Implementation
- Commissioning Provider Assistance
- Owner-led Implementation

Implementation Approaches

Advanced RCx Course

- Turn-key Implementation
  - Commissioning provider manages and oversees all aspects of implementation
  - Commissioning provider carries contract with outside contractors if necessary
  - Commissioning provider verifies and documents results
  - Often the easiest option for owners

Implementation Approaches

Advanced RCx Course

- Commissioning Provider Assistance
  - Owner manages and oversees all aspects of implementation, including in-house staff and outside contractors
  - Commissioning provider offers support and oversight of in-house staff and outside contractors to ensure proper implementation
  - Commissioning provider verifies and documents results
  - Often the easiest option for owners with adequate in-house staff or established relationships with outside contractors

Implementation Approaches

Advanced RCx Course

- Owner-led Implementation
  - Owner manages and oversees all aspects of implementation, including in-house staff and outside contractors
  - Commissioning provider offers support and oversight of in-house staff and outside contractors to ensure proper implementation
  - Commissioning provider verifies and documents results in conjunction with in-house staff
  - Often the best option for owners who adopt a goal of making retrocommissioning “business-as-usual” for additional buildings within a portfolio

Implementation Approaches

Advanced RCx Course

- Brief description of each measure
- Status of the implementation
- Outline future recommendations
  - Training
  - Measure enhancements (e.g. capital projects)
  - Commissioning provider verifies and documents results in conjunction with in-house staff
  - Implement measure at some time in the future

SEE SAMPLE IMPLEMENTATION SUMMARY TABLE

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How Do You Sell It?

- Simple Payback
  - Traditional approach
  - Easy to assess
  - Limited perspective
- Net Operating Income (NOI)
  - The bigger picture

Net Operating Income (NOI)

Gross Income		Operating Expenses
• Rental income • Parking fees • Vending receipts … adjusted for vacancy rate and bad debt	less	• Utilities • Repairs • Maintenance • Insurance • Management fees • Supplies • Taxes

Items and allocations with tenants in both categories vary from owner to owner and lease to lease.

www.canmetenergy.nrcan.gc.ca/RCx_net_operating_income.html

Two Important NOI Relationships

Advanced RCx Course

- A market cap rate is determined by evaluating the financial data of similar properties that have recently sold in a specific market.
- RCx can improve NOI
- Improved NOI has a positive impact on both of these relationships!

Simple payback does not necessarily talk to them

$$\text{Estimated Value} = \frac{\text{Net Operating Income}}{\text{Capitalization Rate}} \qquad \text{Debt Coverage Ratio} = \frac{\text{Net Operating Income}}{\text{Debt Service}}$$

Capitalization Rate	Dept Coverage Ratio
A fraction usually expressed as a percent (i.e. a number less than 1)	1 is break-even; lenders usually require at least 1.1 to 1.3
Smaller is better	Bigger is better

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Module Resume

Advanced RCx Course

- What was learned?
  - How to identify and evaluate savings potential for several common RCx opportunities
  - Various ways to implement identified savings opportunities

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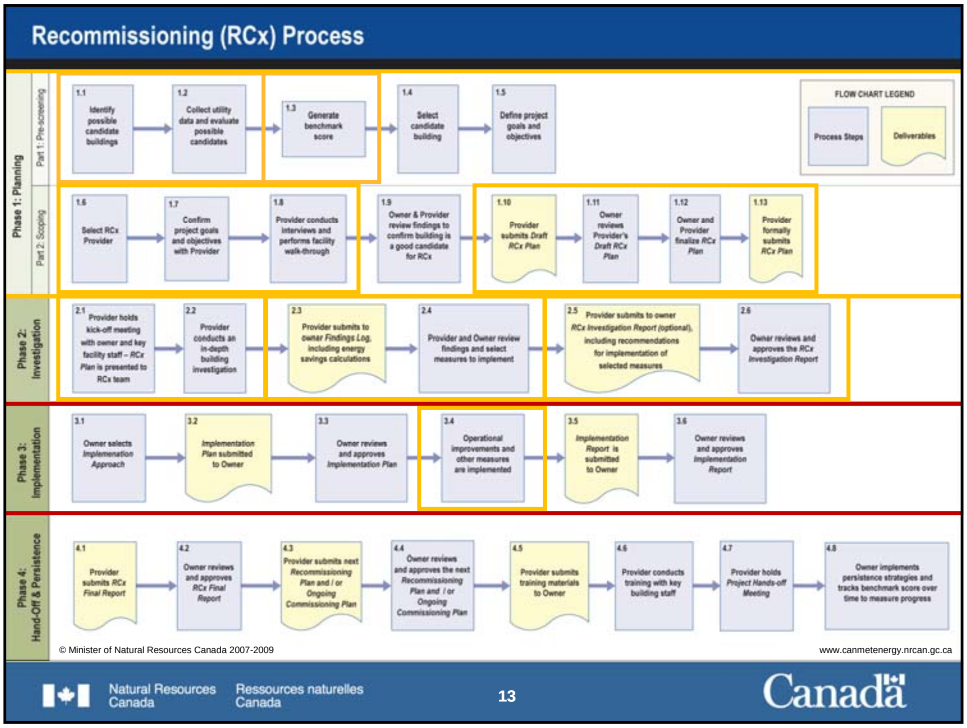
Recommissioning (RCx) Process
Phase 1: Planning
Part 1: Pre-screening
1.1 Identify possible candidate buildings
1.2 Collect utility data and evaluate possible candidates
1.3 Generate benchmark score
1.4 Select candidate building
1.5 Define project goals and objectives
FLOW CHART LEGEND
Process Steps
Deliverables
Part 2: Scoping
1.6 Select RCx Provider
1.7 Confirm project goals and objectives with Provider
1.8 Provider conducts interviews and performs facility walk-through
1.9 Owner & Provider review findings to confirm building is a good candidate for RCx
1.10 Provider submits Draft RCx Plan
1.11 Owner reviews Provider's Draft RCx Plan
1.12 Owner and Provider finalize RCx Plan
1.13 Provider formally submits RCx Plan
Phase 2: Investigation
2.1 Provider holds kick-off meeting with owner and key facility staff – RCx Plan is presented to RCx team
2.2 Provider conducts an in-depth building investigation
2.3 Provider submits to owner Findings Log, including energy savings calculations
2.4 Provider and Owner review findings and select measures to implement
2.5 Provider submits to owner RCx Investigation Report (optional), including recommendations for implementation of selected measures
2.6 Owner reviews and approves the RCx Investigation Report
Phase 3: Implementation
3.1 Owner selects Implemenation Approach
3.2 Implementation Plan submitted to Owner
3.3 Owner reviews and approves Implementation Plan
3.4 Operational improvements and other measures are implemented
3.5 Implementation Report is submitted to Owner
3.6 Owner reviews and approves Implementation Report
Phase 4: Hand-Off & Persistence
4.1 Provider submits RCx Final Report
4.2 Owner reviews and approves RCx Final Report
4.3 Provider submits next Recommissioning Plan and / or Ongoing Commissioning Plan
4.4 Owner reviews and approves the next Recommissioning Plan and / or Ongoing Commissioning Plan
4.5 Provider submits training materials to Owner
4.6 Provider conducts training with key building staff
4.7 Provider holds Project Hands-off Meeting
4.8 Owner implements persistence strategies and tracks benchmark score over time to measure progress
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Building Operation Optimization

Advanced Recommissioning (RCx) Course

Phase 4: Hand-Off and Persistence

Developed by Portland Energy Conservation, Inc.

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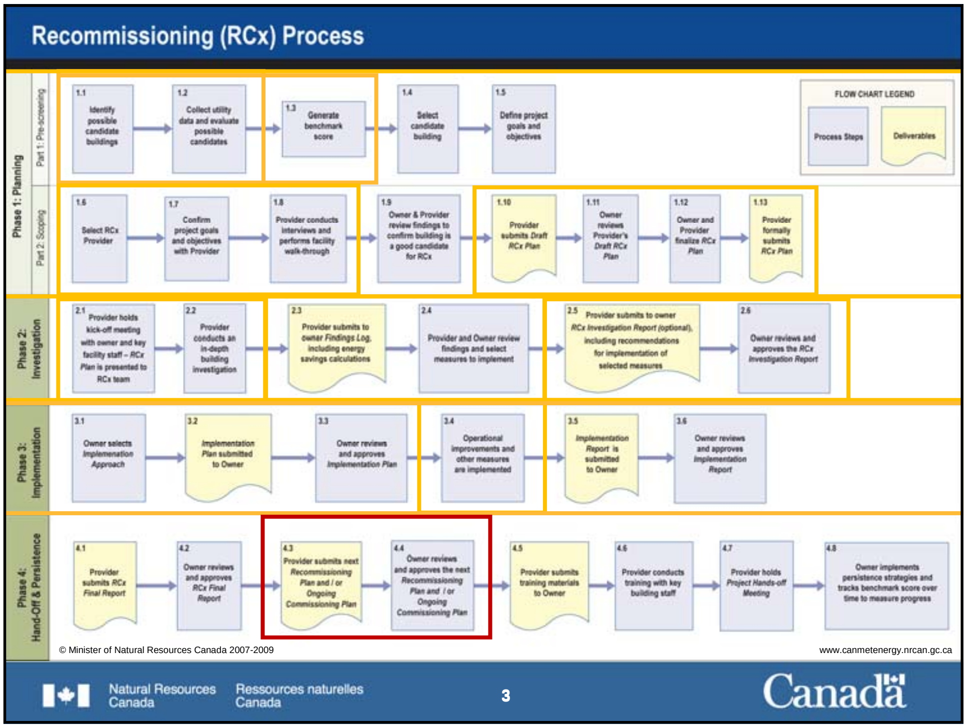
Preview

- Where have we been?
  - Planning phase
  - Investigation phase
  - Implementation phase
- What's next?
  - Hand-off and persistence phase

ACTIVITY

Develop enhanced sequence of operations and persistence matrix

- Discuss RCx Plan



Hand-off Phase

Advanced RCx Course

- Develop ongoing Commissioning Plan
  - Identify key persistence strategies
    - ➢Track energy and re-benchmark
    - ➢Update building documentation
    - ➢Develop Enhanced O&M Action Plan
    - ➢Train building staff

SEE SAMPLE OPERATIONAL PERSISTENCE MATRIX (6 SHEETS)

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Hand-off Phase

Advanced RCx Course

- Develop the next Recommissioning Plan
  - Next re-optimization process for buildings
  - Ensures building equipment and systems are operating optimally to meet current occupant needs
  - Ensures qualified staffs are adequately committed to implementing the RCx plan

RESOURCE

Strategies for Improving Persistence of Commissioning Benefits
www.canmetenergy.nrcan.gc.ca/RCx_CACx_library.html

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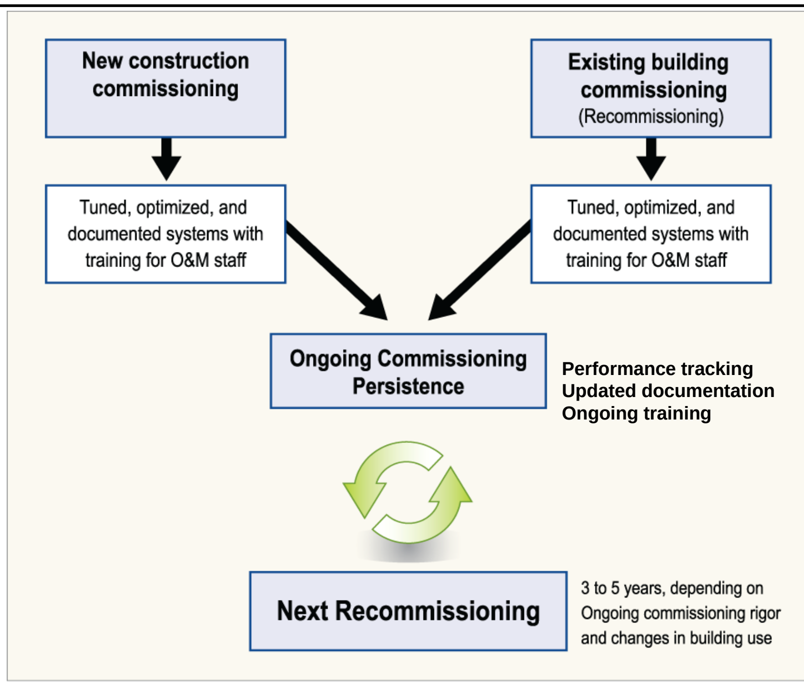

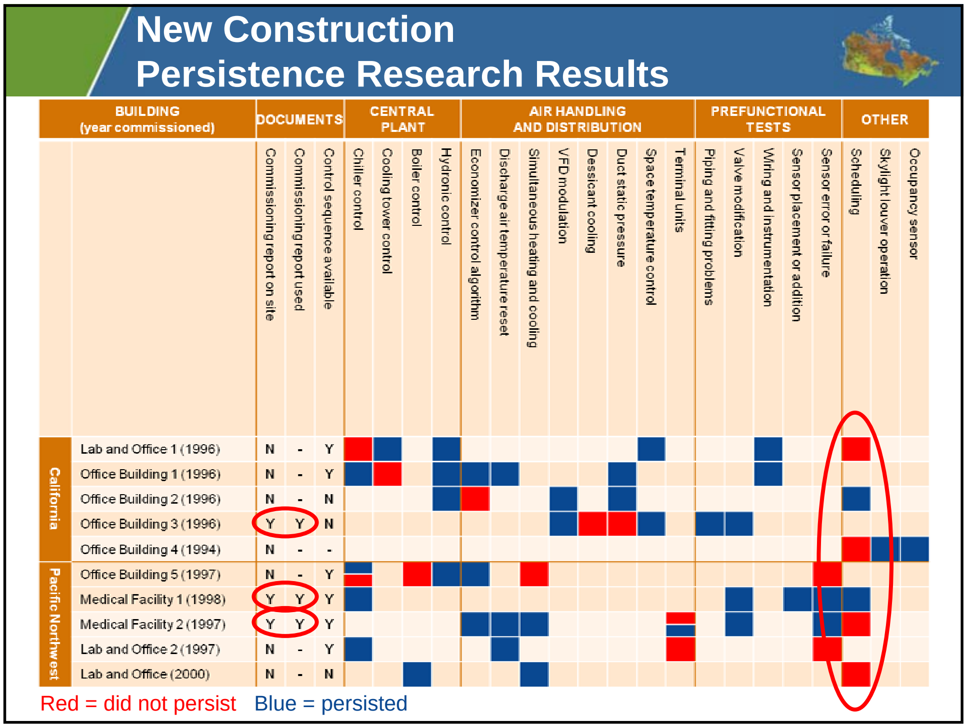

Persisted

- **70% of measures studied**
  - Deep programming code changes
  - Hardware/physical changes

Didn't Persist

- Occupancy schedules
- CHW reset schedule
- VAV box programming
- VFD min. speed setting
- Humidity sensor calibration
- Daylighting controls
- Demand control ventilation
- Evaporative cooling
- Desiccant wheel

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Track energy and re-benchmark

Advanced RCx Course

- Use post-recommissioning utility data and benchmarking tools identified during scoping to develop a building baseline
- Follow International Performance Measurement and Verification Protocol (IPMVP)
  - Option A – Stipulations
  - Option B – End-use measurements and analysis
  - Option C – Whole-building utility data analysis
  - Option D – Calibrated simulations

Update Building Documentation

Advanced RCx Course

- Updated sequence of operations

SEE SAMPLE OVERALL BUILDING OPERATIONS PLAN:
Courthouse – Building Sequence of Operation (10 sheets)

- System diagrams
- Master list of all findings and status of implementation

SEE SAMPLE IMPLEMENTATION SUMMARY MATRIX – FINAL:
Implementation Summary Matrix (3 sheets)

- Trending plan (part of Ongoing RCx Plan)
  - What points to look at
  - How frequently
  - Trend collection interval

Enhanced O&M Action Plan

Advanced RCx Course

- Revise O&M tasks and schedule
  - Target specific O&M opportunities identified during recommissioning
  - Expand current preventive maintenance tasks
  - Expand use of existing EMS to help troubleshoot and warn of operational problems
- Enhance O&M practices
  - Implement benchmarking strategies
  - Ongoing operator training
  - Define clear roles/responsibilities for outside service contractors

Building Staff Training

Advanced RCx Course

- Go over revised sequence of operations
  - Understand how the system really operates and how to spot operational issues
- Go over enhanced O&M practices
- Go over “best practices” for making adjustments to the control sequences
  - Document setpoint adjustments and all control modifications

SEE SAMPLE ONGOING RCx PLAN:
Courthouse – Calibration and Maintenance Checks for RCx – Metric Units (3 sheets) and Imperial Units (2 sheets)

- Consider videotaping all training sessions

Activity

Advanced RCx Course

- Separate into small groups
- Develop enhanced sequence of operations and persistence matrix
  - What to look for
  - What to look at
  - What to do about it
- Discuss each group's matrix as a class

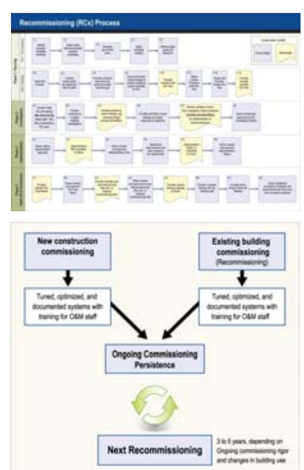
SEE ACTIVITY SHEET:

Develop enhanced sequence of operations and persistence matrix (1 sheet)

Suppose the RCx process is adequately completed

Advanced RCx Course

- Measures are implemented
- Treated systems are operating at their optimized performance level
- Building operators are committed to and can maintain the persistence of the implemented measures
- *Why have benefits not persisted?*
- *What has to be done after that to ensure persistence of RCx benefits (savings)?*



Why benefits don't persist?

Advanced RCx Course

- Degradation and failure of equipment
- Facility use changes
- Testing of Cx measures generally does not include seasonal extremes/variations
- Overriding of control strategy and setpoint
- Lack of maintenance
  - Operators constantly 'fighting fires'
  - HVAC systems and control sequences more complex
  - Energy billing methods are more complex
  - Loss of performance is not always visible or easily measurable
  - Energy is far from the focus of attention

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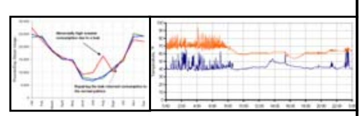
To ensure persistence

Advanced RCx Course

- Have an ongoing structured persistence approach
- Re-evaluate building usage and system operation
  - When major remodel or change in systems
  - When major change in building use
  - At least every 3 to 5 years
- Track performance (e.g. persistence of savings)
  - Detect deviations from the expected system performance
- Resolve problems
  - Ensuring problem actually exists
  - Visiting the building to gather additional information
  - Acting to correct the problem
- Update documentations and re-benchmark as needed



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Track performance

Advanced RCx Course

- To detect deviations from the expected system performance
  - Compile comfort complaints (daily basis)
  - Track energy use to monitor changes (monthly basis)
  - Perform tasks on the “Persistence Check List” (monthly basis)
  - Detect faults that can avoid operation of optimal control strategy (continuous basis)
  - Monitor RCx measures by using the existing building automation system trending capabilities or independent data loggers — refer to the RCx plan to know what points to look at, how frequently, and trend collection interval (at least every 3 months)

Benefits that may not persist

Advanced RCx Course

- Benefits that are difficult to quantify
  - Ensure proper system performance (energy and non-energy systems)
  - Increase in-house staff skills, knowledge, awareness
  - Increase occupant productivity
- Benefits that are quantifiable
  - Reduce energy consumption
  - Ensure or improve indoor thermal environment /occupant comfort
  - Ensure adequate indoor air quality

Track performance of benefits that are difficult to quantify

Advanced RCx Course

- Persistence shall be determined by comparing a list of documented Cx measures that were implemented during the Cx process with the measures that are subsequently documented as being in place or operational during the time when persistence is being checked. **(yes/no check list)**

Verification Check List

System	Measure	Verify
AH1	Minimum airflow reset base on CO_2 sensor	✓
AH1	Supply air temperature reset base on maximum zone load	✓
AH1	Supply pressure setpoint rest base on VAV box damper position	

Track performance of benefits that are quantifiable

Advanced RCx Course

- Persistence of thermal comfort and indoor air quality benefits
  - Benefit may be evaluated in terms of specific improvements in comfort or indoor air quality provided sufficient baseline measurements of these conditions are made
  - ASHRAE Standards 55 and 62 (ASHRAE 2004a)

Verification Check List

System	Energy, Water and Comfort Reference	Verify
Chiller 1	kW/tonne conform to estimate patern	✓
Building	Monthly peak demand	✓

Track energy use

Advanced RCx Course

- To be performed on a monthly basis with normalized data

  Energy Savings = (base year energy use)
  – (post-retrofit energy use)
  ± adjustments

- Compare the curves for different years
- For more sophisticated techniques: International Performance Measurement and Verification Protocol (IPMVP)
- Tools that automate utility tracking: Energy Information Systems (EIS)

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Energy Information Systems (EIS)

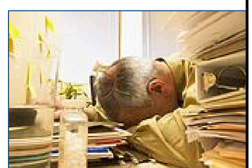
Software	Vendor / Developer	EIS Types: Utility-EIS	EEM	DRS	Web-EMCS
AMICOS	Southern California Edison	✓			
AES-IntelliNet	AES Corporation	✓			
Enerlink.net	SCT Corporation	✓			
Demand Exchange	Apogee Interactive	✓		✓	
Readmeter/Loadcontrol	Cannon Technologies	✓		✓	
EP Web	ELutions	✓		✓	
Energy Profiler Online	ABB	✓	✓	✓	
PLISEM	Plurimi			✓	
energy1st	Stonewater Software	✓		✓	
Load Profiler	Automated Energy	✓	✓		
UtilityVison	CMS Viron	✓	✓	✓	
EEM Suite	Silicon Energy	✓	✓	✓	✓
EnterpriseOne	Circadian Information Systems	✓	✓		✓
Intelligent Use of Energy	WebGen Systems	✓		✓	✓

Source: Friedman, et al. “Strategies for Improving Persistence of Commissioning Benefits” June 2003.

Trend analysis

Advanced RCx Course

- Learning curve is important
  - Interpreting and following up with troubleshooting are equally important
  - Becoming familiar with trends and data is half the battle
- Trending prioritization
  - Systems with current comfort or operational problems
  - Systems suspected of faulty operation
  - Areas that tend to have problems (e.g. economizers)
  - Systems that consume large amounts of energy
  - Systems that have recently been repaired or retrofitted
- Write a trending plan that indicates points to read, sampling rate and plan for analyzing the data
- Could easily become an overwhelming task
  - Example: 50 points over 3 months



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Sample trending and analysis plan

Issue or Equipment	Points to Trend	Sampling Interval	Analysis Summary
Unnecessary equipment operation	Change of value (COV), another indicator or an ON condition Time-series also works well.	COV or time-series 15 min.	Make sure HVAC is not unnecessarily on outside of occupancy periods. Verify that lighting ON times match HVAC.
Chiller efficiency	Primary chilled water and condenser flow (or values in TAB or start-up report), entering and leaving chilled water temp and chiller kW (or current). For reference, also condenser water supply and return temps.	15 min.	Calculate the kW/ton of cooling. Plot kW/ton vs. chiller % load as a benchmark. During similar weather next season, see if the kW/ton remains the same or is degrading (possibly indicating fouling). Compare to manufacturer's kW/ton.
Terminal unit	Zone temperature, heating coil valve position and command, air cfm or damper position, cfm setpoint. The outside temp and duct static pressure may also need to be trended.	2 min.	Plot with two Y-axes for resolution. Observe that the zone temperature remains within 1°F of the deadband, the cfm is not over or undershooting its setpoint or hunting, the heating valve is not hunting, and the cfm is at minimum before the heating valve opens.

TAB = Testing and Balancing

Source: Friedman, et al. "Strategies for Improving Persistence of Commissioning Benefits", June 2003.

Energy Management Control System (EMCS)

Advanced RCx Course

- Computer software to analyse trend data, detect problems, and even suggest solutions
- Some can tell when the problem occurred, at which piece of equipment, and for how long
- Allow for continuous monitoring and diagnostics

FOR MORE INFORMATION:
www.canmetenergy.nrcan.gc.ca/PECI_Tools_Guide.html

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Next RCx Plan

Advanced RCx Course

- Re-evaluate building usage and system operation
  - Best if performed by 3rd party
    - At least every 3 to 5 years
    - Major remodel or change in systems
    - Major change in building use
  - Update building documentation as necessary
- Revise ongoing commissioning (persistence) plan as necessary
- Provide operator training as necessary

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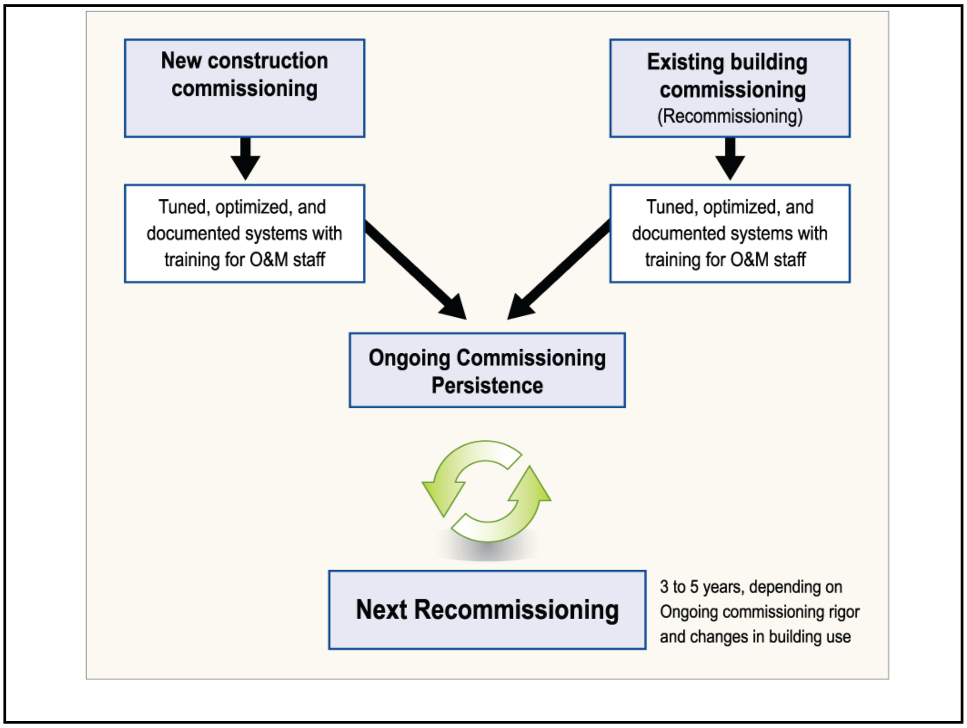
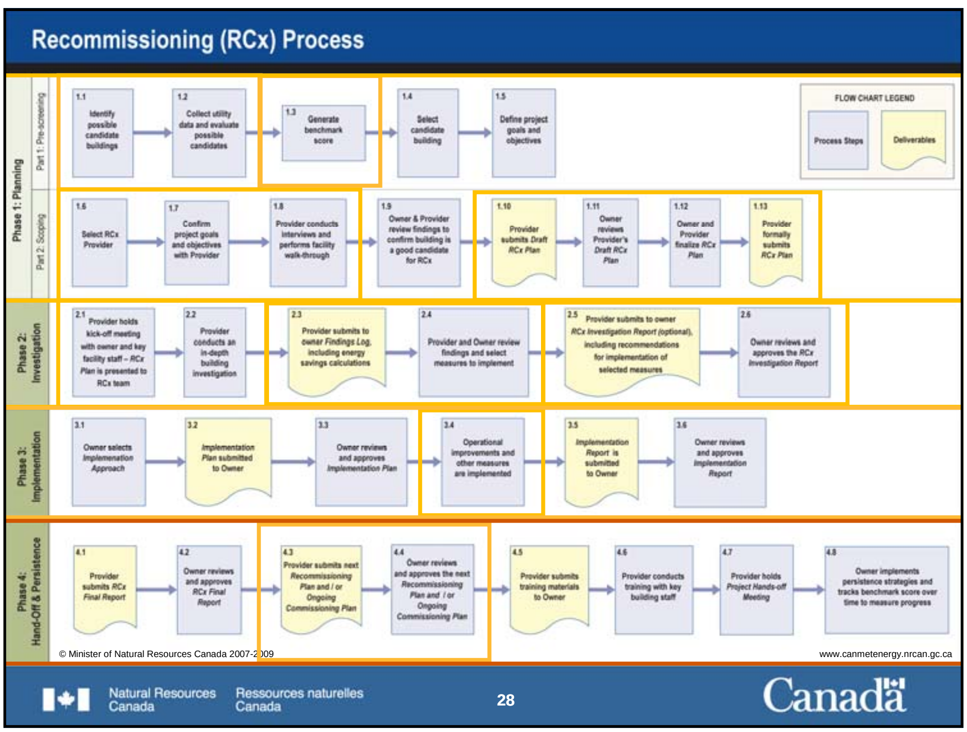

New construction commissioning
Existing building commissioning (Recommissioning)
Tuned, optimized, and documented systems with training for O&M staff
Tuned, optimized, and documented systems with training for O&M staff
Ongoing Commissioning Persistence
Next Recommissioning
3 to 5 years, depending on Ongoing commissioning rigor and changes in building use


Recommissioning (RCx) Process
Phase 1: Planning
Part 1: Pre-screening
1.1 Identify possible candidate buildings
1.2 Collect utility data and evaluate possible candidates
1.3 Generate benchmark score
1.4 Select candidate building
1.5 Define project goals and objectives
FLOW CHART LEGEND
Process Steps
Deliverables
Part 2: Scoping
1.6 Select RCx Provider
1.7 Confirm project goals and objectives with Provider
1.8 Provider conducts interviews and performs facility walk-through
1.9 Owner & Provider review findings to confirm building is a good candidate for RCx
1.10 Provider submits Draft RCx Plan
1.11 Owner reviews Provider's Draft RCx Plan
1.12 Owner and Provider finalize RCx Plan
1.13 Provider formally submits RCx Plan
Phase 2: Investigation
2.1 Provider holds kick-off meeting with owner and key facility staff – RCx Plan is presented to RCx team
2.2 Provider conducts an in-depth building investigation
2.3 Provider submits to owner Findings Log, including energy savings calculations
2.4 Provider and Owner review findings and select measures to implement
2.5 Provider submits to owner RCx Investigation Report (optional), including recommendations for implementation of selected measures
2.6 Owner reviews and approves the RCx Investigation Report
Phase 3: Implementation
3.1 Owner selects Implemenation Approach
3.2 Implementation Plan submitted to Owner
3.3 Owner reviews and approves Implementation Plan
3.4 Operational improvements and other measures are implemented
3.5 Implementation Report is submitted to Owner
3.6 Owner reviews and approves Implementation Report
Phase 4: Hand-Off & Persistence
4.1 Provider submits RCx Final Report
4.2 Owner reviews and approves RCx Final Report
4.3 Provider submits next Recommissioning Plan and / or Ongoing Commissioning Plan
4.4 Owner reviews and approves the next Recommissioning Plan and / or Ongoing Commissioning Plan
4.5 Provider submits training materials to Owner
4.6 Provider conducts training with key building staff
4.7 Provider holds Project Hands-off Meeting
4.8 Owner implements persistence strategies and tracks benchmark score over time to measure progress
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Building Operation Optimization
Advanced Recommissioning (RCx) Course

Conclusion

Developed by Portland Energy Conservation, Inc.

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Adapted by Natural Resources Canada's CanmetENERGY
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Overall Course Wrap-up

Advanced RCx Course

What have we covered and accomplished?

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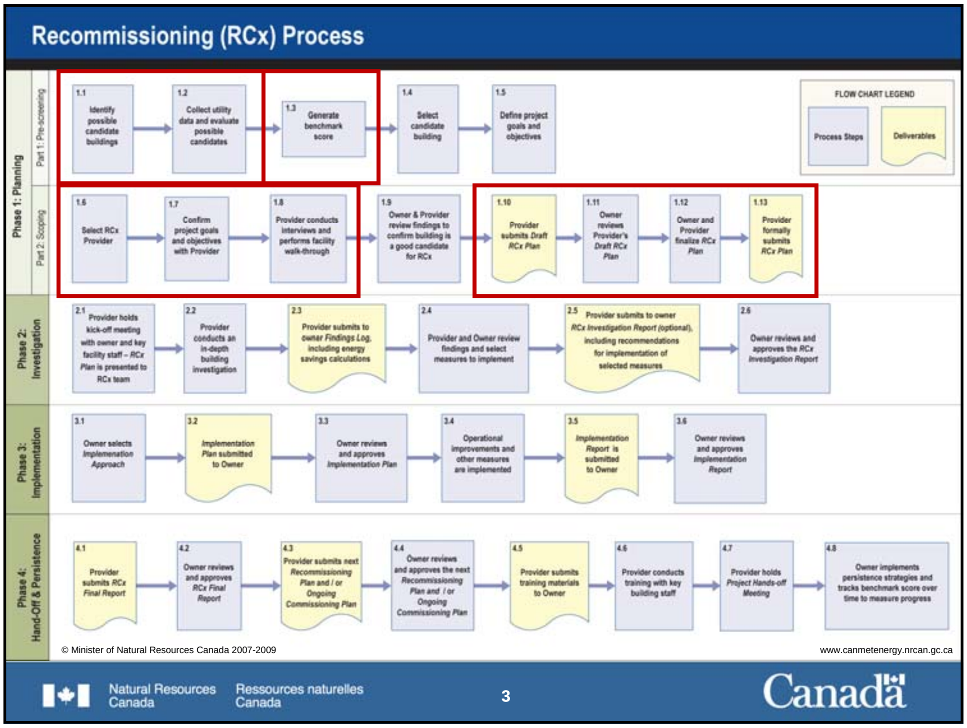

Planning Phase
Key Accomplishments

Advanced RCx Course

We have:

- Discussed how to screen a building to ensure maximum benefit from the retrocommissioning process;
- Learned the methods and value of benchmarking building energy usage;
- Learned techniques that can be used to scope a building effectively;
- Discussed how to make effective use of both trend data and stand-alone data loggers; and
- Developed a RCx plan to help prioritize the tasks to be performed during the detailed investigation.

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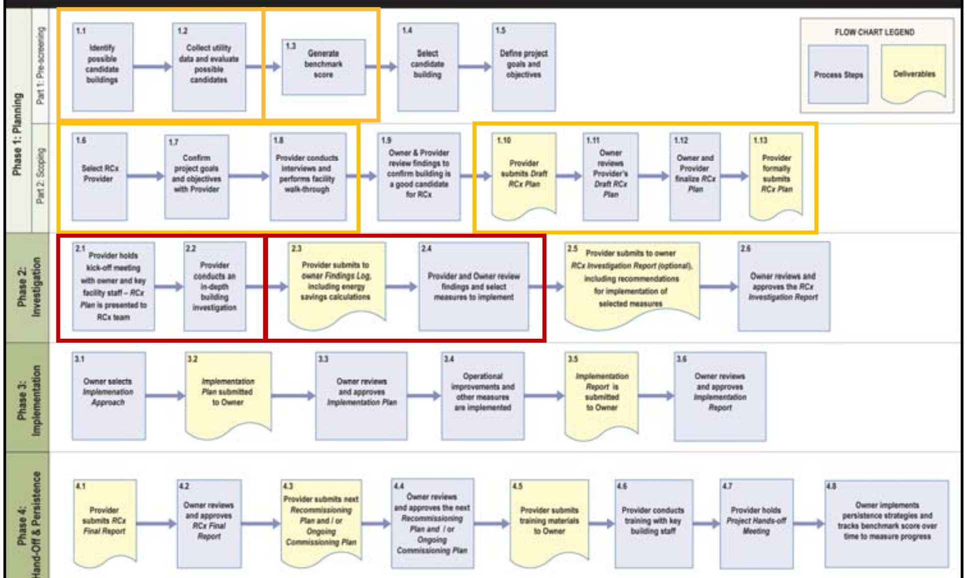
Recommissioning (RCx) Process



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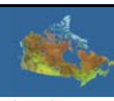
Investigation Phase
Key Accomplishments

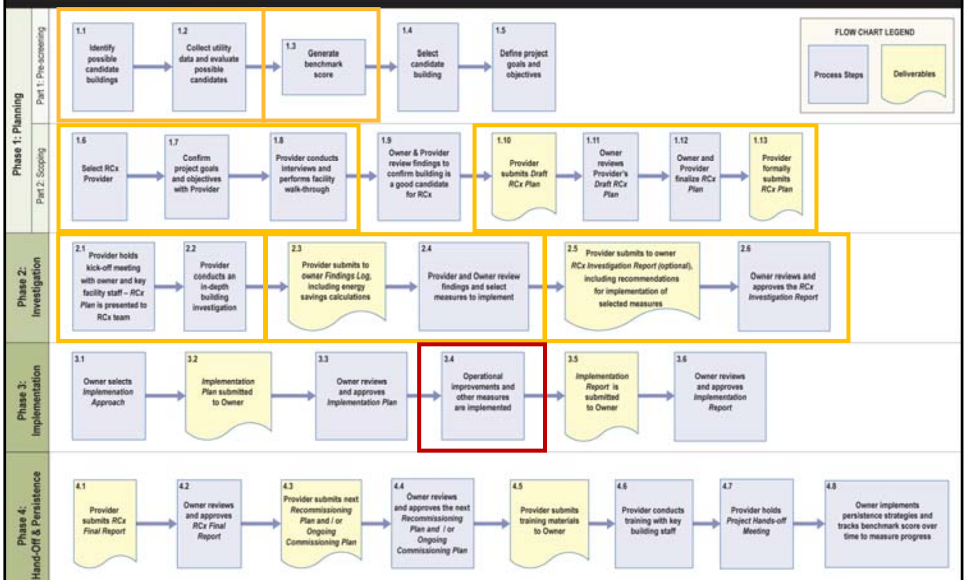


Advanced RCx Course

We have:

- Discussed useful engineering fundamentals and theory;
- Learned the value of developing system diagrams;
- Learned how to execute a pump test;
- Performed a detailed pumping analysis and evaluated the savings potential; and
- Learned how to identify and estimate savings potential for several common operational problems found in buildings.
  - Schedules
  - Improper set-points
  - Ventilation opportunities
  - Reset control strategy interactions and remedies
  - Economizer control issues
  - Cooling tower reset

Recommissioning (RCx) Process



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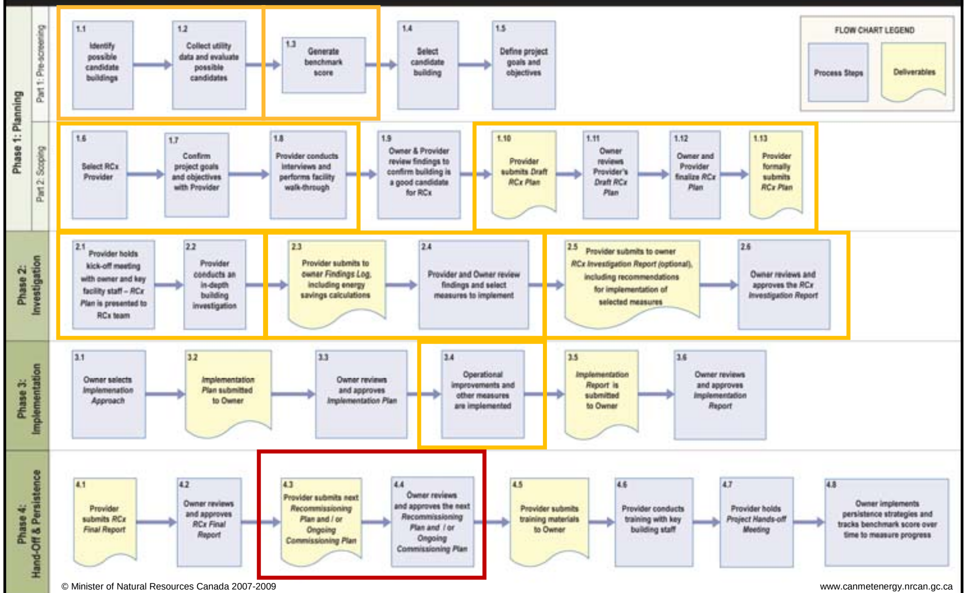
Implementation Phase Key Accomplishments

Advanced RCx Course

We have:

- Learned successful implementation techniques
- Learned how to make sure measures implemented through the retrocommissioning process will persist over time
  - Building operation plan
  - Enhance documentation
  - Facility staff training
  - Development of an ongoing commissioning plan

Recommissioning (RCx) Process



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Hand-off Phase
Key Accomplishments

Advanced RCx Course

We have:

- Learned how to make sure measures implemented through the recommissioning process will persist over time
  - Building operation plan
  - Enhance documentation
  - Facility staff training
  - Development of an ongoing commissioning plan
  - Development of the next recommissioning plan
- Developed enhanced sequence of operations
- Developed a persistence matrix

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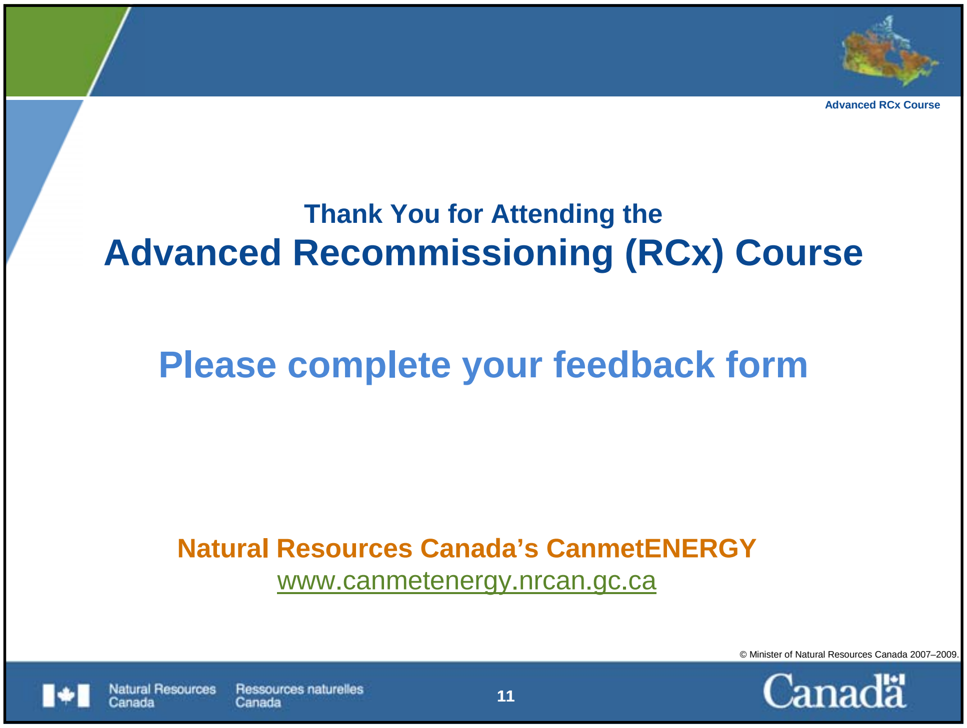
Advanced RCx Course
Thank You for Attending the
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ENERGY CONVERSION TABLES[41]

The following conversion tables of commonly used units are provided for the convenience of people who may be more familiar with the Imperial System.

Common Units

Crude Oil and Natural Gas Liquids

Abbreviation	Description
b/d	barrels per day
bbl	barrels
m^3	cubic metre
m^3/d	cubic metres per day
Mb/d	thousand barrels per day
MMb	million barrels
MMb/d	million barrels per day

Natural Gas

Abbreviation	Description
Bcf	billion cubic feet
Bcf/d	billion cubic feet per day
Btu/cf	British thermal units per cubic feet
cf	cubic feet
m^3	cubic metre
m^3/d	cubic metres per day
Mcf	thousand cubic feet
MMBtu	million British thermal units
MMcf	million cubic feet
MMcf/d	million cubic feet per day
Tcf	trillion cubic feet

41 National Energy Board Website: www.neb.gc.ca/clf-nsi/rnrgynfmtn/sttstc/nrgycnvrsntbl/nrgycnvrsntbl-eng.html

Electricity

Abbreviation	Description
MW	megawatt
kWh	kilowatt hour
MWh	megawatt hour
GWh	gigawatt hour
TWh	terawatt hour

Common Conversions

From	To	Multiply By
metres (m)	feet	3.2808
kilometres (km)	miles	0.621
hectares (ha)	acres	2.471
kilograms (kg)	pounds	2.205
cubic metres (m^3)	barrels (oil or natural gas liquids)	6.292
cubic metres (m^3)	cubic feet of natural gas (@ 14.73 psia and 60°F)	35.301
litres (L)	US gallons	0.265
litres (L)	imperial gallons	0.220
imperial gallons	US gallons	1.201
barrels (bbl)	US gallons	42.0
barrels (bbl)	imperial gallons	34.972
metric tonnes (t)	pounds	2204.6
kilometers/litre	miles/gallon	2.825
gigajoules (GJ)	million British thermal units	0.95

Prefixes and Equivalents

From		Equivalent
k	(kilo)	10^3
M	(mega)	10^6
G	(giga)	10^9
T	(tera)	10^{12}
P	(peta)	10^{15}
E	(exa)	10^{18}

Energy Content

The energy content of a 30-litre tank of gasoline is approximately one gigajoule or 0.95 million Btu of energy. A petajoule is one million gigajoules. On average, Canada consumes about one petajoule of energy every 50 minutes for all uses (heat, light and transportation) for both commercial and residential use.

Energy

Unit	Equivalent to
gigajoule (GJ)	10^9 joules 0.95 million Btu 0.95 thousand cubic feet of natural gas at 1000 Btu/cf 0.165 barrels of oil 0.28 megawatt hour of electricity

Crude Oil

Unit	Equivalent to
1 cubic metre (m^3) (pentanes plus)	35.17 GJ
1 cubic metre (m^3) (light)	38.51 GJ
1 cubic metre (m^3) (heavy)	40.90 GJ

Natural Gas

Unit	Equivalent to
1 cubic metre (m^3)	35.301 cubic feet @ 14.73 psia and 60°F
thousand cubic feet (Mcf)	1.05 GJ
million cubic feet (MMcf)	1.05 TJ
billion cubic feet (Bcf)	1.05 PJ
trillion cubic feet (Tcf)	1.05 EJ

Natural Gas Liquids

Unit	Equivalent to
1 cubic metre (m^3) (ethane)	18.36 GJ
1 cubic metre (m^3) (propane)	25.53 GJ
1 cubic metre (m^3) (butane)	28.62 GJ

Electricity

Unit	Equivalent to
gigawatt hour (GWh)	10^6 kWh 3 600 GJ 0.0036 PJ
kilowatt hour (kWh)	0.0036 GJ
megawatt hour (MWh)	3.6 GJ
terawatt hour (TWh)	10^9 kWh or 3.6 PJ

Coal

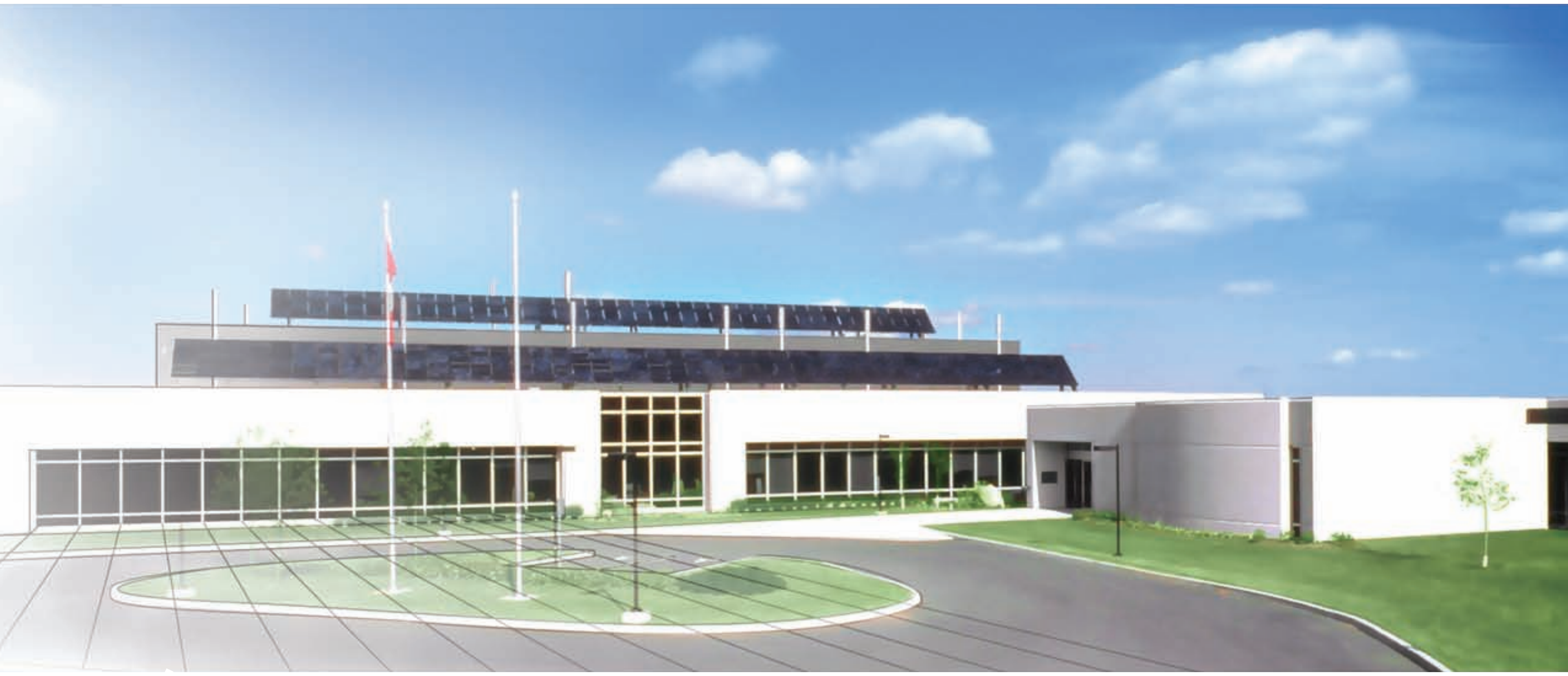
Unit	Equivalent to
1 tonne (t) (anthracite)	27.70 GJ
1 tonne (t) (bituminous)	27.60 GJ
1 tonne (t) (lignite)	14.40 GJ
1 tonne (t) (subbituminous)	18.80 GJ
trillion cubic feet (Tcf)	1.05 EJ

Petroleum Products

Unit	Equivalent to
1 cubic metre (m^3) (asphalt)	44.46 GJ
1 cubic metre (m^3) (aviation gasoline)	33.52 GJ
1 cubic metre (m^3) (aviation turbo fuel)	35.93 GJ
1 cubic metre (m^3) (diesel)	38.68 GJ
1 cubic metre (m^3) (heavy fuel oil)	41.73 GJ
1 cubic metre (m^3) (kerosene)	37.68 GJ
1 cubic metre (m^3) (light fuel oil)	38.68 GJ
1 cubic metre (m^3) (lubes and greases)	39.16 GJ
1 cubic metre (m^3) (motor gasoline)	34.66 GJ
1 cubic metre (m^3) (naphtha specialties)	35.17 GJ
1 cubic metre (m^3) (petrochemical feedstock)	34.17 GJ
1 cubic metre (m^3) (petroleum coke)	42.38 GJ
1 cubic metre (m^3) (still gas)	41.73 GJ
1 cubic metre (m^3) (other products)	39.82 GJ

Other Fuels

Unit	Equivalent to
1 cubic metre (m^3) (ethanol)	23.60 GJ
1 cubic metre (m^3) (hydrogen)	0.12 GJ
1 cubic metre (m^3) (methanol)	15.60 GJ



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