Final version of algorithms for most common ECO`s

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By

Janez Mandelj, Matjaž Prek

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iSERVcmb Project Team

Welsh School of Architecture, Cardiff University UK (Project co-ordinator)	K2n Ltd UK
MacWhirter Ltd UK	National and Kapodistrian University of Athens Greece
University of Porto Portugal	Politecnico di Torino Italy
Université de Liège Belgium	University of Ljubljana Slovenia
University of Pecs Hungary	Austrian Energy Agency Austria
REHVA UK	CIBSE UK

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1 Introduction

As identified in AUDITAC and HARMONAC, an ECO is an Energy Conservation Opportunity that exists for a Heating, Ventilation or Air Conditioning (HVAC) system – specifically AC systems in the two projects noted. Energy savings of up to 60% were quantified by AUDITAC and HARMONAC for individual ECOs for AC systems, and savings of around 30 – 40% were regularly encountered.

This task presents the continuation of the HarmonAC project in terms of automatic identification, analysis of the possibility for implementation and evaluation of ECO's. It forms the last part of the feedback to the system owner by suggesting which ECO's might be applicable to the specific situation existing for the system, and the range of savings that might be achieved if they were implemented.

This part of the iSERV project is directed to helping specific system managers and owners to identify and implement energy-saving opportunities. It is therefore their perspective that we need to consider. The purpose of this work package was to establish what information each ECO needs to identify it as a possibility for a specific system and end use, and then write the algorithm code necessary to automatically identify those ECO's that may be identifiable from the information being collected online.

Algorithms may relate to static data (such as system descriptions), dynamic data (such as daily, hourly or sub-hourly data, and derived variables from this), or modeling results. Any ranking of priorities is bound to be fairly "rough and ready" but it is important to assign effort to those ECOs that seem to be most important.

Algorithms serve two purposes: to identify the existence of ECOs and to estimate the potential savings associated with them. Comparison of annual consumption benchmarks to the observed consumption of a specific system shows (more or less) the size of the overall savings opportunity. By estimating the savings from identified ECOs we can see (also approximately) what proportion of this opportunity has been identified, and how much remains unexplained.

Advice from the Steering Group reinforces the general expectation that most managers and owners are primarily concerned with financial issues, expressed in terms of capital cost and payback time, preferring low initial expenditure and/or short payback times.

For energy conservation measures, pay-back period is usually a good proxy for internal rate of return: short payback indicating high rate of return. Regulators usually use other metrics such as the cost of carbon abated or life-cycle net value to society (ideally ignoring taxes and subsidies but including shadow prices for unpriced impacts such as climate change). Life-cycle net present values usually ignore risk issues and the opportunity cost of capital (the returns that would be available by making other investments). They almost always assume a "typical" user and application for whom the circumstances may differ considerably from hose of a particular owner. Energy efficiency regulation is commonly intended to make individuals take measures (or desist from practices) that are believed to be in the interests of society as a whole but not perceived to be attractive to individuals or organizations.

From the definition of payback, it is easy to see that the biggest savings per implemented ECO are for high capital cost, short payback measures.

So there is a trade-off which depends on the sensitivity of take-up to cost and payback: in economics language, to the "price (or payback) elasticity of demand". When the two effects are combined, it turns out that the largest aggregate savings (savings per ECO implemented x take-up rate) are associated with the lowest paybacks. So payback is the primary factor to consider

2 List of ECO`s by priorities

ECOs have been assigned an approximate relative payback rating and a similar capital cost rating. These have then been sorted, firstly by payback and then by capital cost (lowest to highest in each case).

Priority Rankings for Algorithms			
ECO		Capex	Payback
Priority 1			
O2.2	Shut off A/C equipment when not needed	Low	Low
O2.3	Shut off auxiliaries when not required	Low	Low
O3.1	Shut chiller plant off when not required	Low	Low
Priority 2			
P1.3	Modify controls in order to sequence heating and cooling	Low/Medium	Low/Medium
P1.7	Reduce power consumption of auxiliary equipment	Low/Medium	Low/Medium
P2.3	Split the load among various chillers	Low/Medium	Low/Medium
P3.6	Apply variable flow rate fan control	Low/Medium	Low/Medium
P4.5	Install variable volume pumping	Medium	Low/Medium
Priority 3			
P2.5	Improve central chiller / refrigeration control	Low	Medium
P3.7	Consider conversion to VAV	Low	Medium
O4.2	Perform night time ventilation	Low	Medium
Priority 4			
P2.2	Reduce compressor power or fit a smaller compressor	High	Medium/high
Priority 5			
P3.12	Replace ducts when leaking	High	High
O4.6	Eliminate air leaks (AHU, packaged systems)	High	High
Priority other			
P2.4	Repipe chillers or compressors in series or parallel to optimize circuiting	High	High
P2.13	Consider cool storage applications (chilled water, water ice, other changing materials)	High	Medium/high
P3.1	Reduce motor size (fan power) when oversized	High	Medium/high
O2.7	Sequence heating and cooling	High	Medium/high
O3.3	Operate chillers or compressors in series or parallel	High	Medium/high
O3.14	Check (reversible) chiller stand-by losses	High	Medium/high
O4.14	Clean or replace filters regularly	High	Medium/high
O4.19	Switch off circulation pumps when not required	High	Medium/high

3 Final version of algorithms for ECO`s - Priority 1

3.1 O2.2 Shut off A/C equipment's when not needed

3.1.1 Existing subsystems on which the ECO may apply

- Water-Based system, Air and water based system

3.1.2 Considered actions

- To upgrade operating control
- To shut down A/C equipment in case where there is no need for operation

3.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

To identify controller manufacturer and search for controller user's guide for cooling control.

- Climatic file
- T – set point of indoor air temperature

3.1.4 Technical observations to be made on site

You can search for temperature when cooling is started (T_1) and when cooling is stopped (T_2).

3.1.5 Monitoring of existing situations

- T- outdoor air temperature
- T – indoor air temperature
- Condition of valve for cooling
- Electrical consumption of each A/C equipment
- Number of functioning hours for each A/C equipment
- Nominal consumption of each A/C equipment

3.1.6 Criterion for ECO applicability

You have to check if the A/C is shut down in two cases:

- When outdoor temperature is lower than set temperature
- When mode of operation is not set.

You also have to check if mode of operation is set correctly.

3.1.7 Recommendation for realization of ECO

You should train considered operators to have an energy-efficient O&M activities (ECO O1.3).

You could examine measured electrical power of A/C equipment for each day, weekend, month and year to find out if the measurements show any deviations.

You could examine before:

- A/C equipment is correctly controlled and mode of operation is set correctly.

You could shut down A/C equipment when to new improvement.

3.1.8 Additional support

3.1.9 Remarks

3.1.10 Input data required for ECO identification

3.1.10.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling

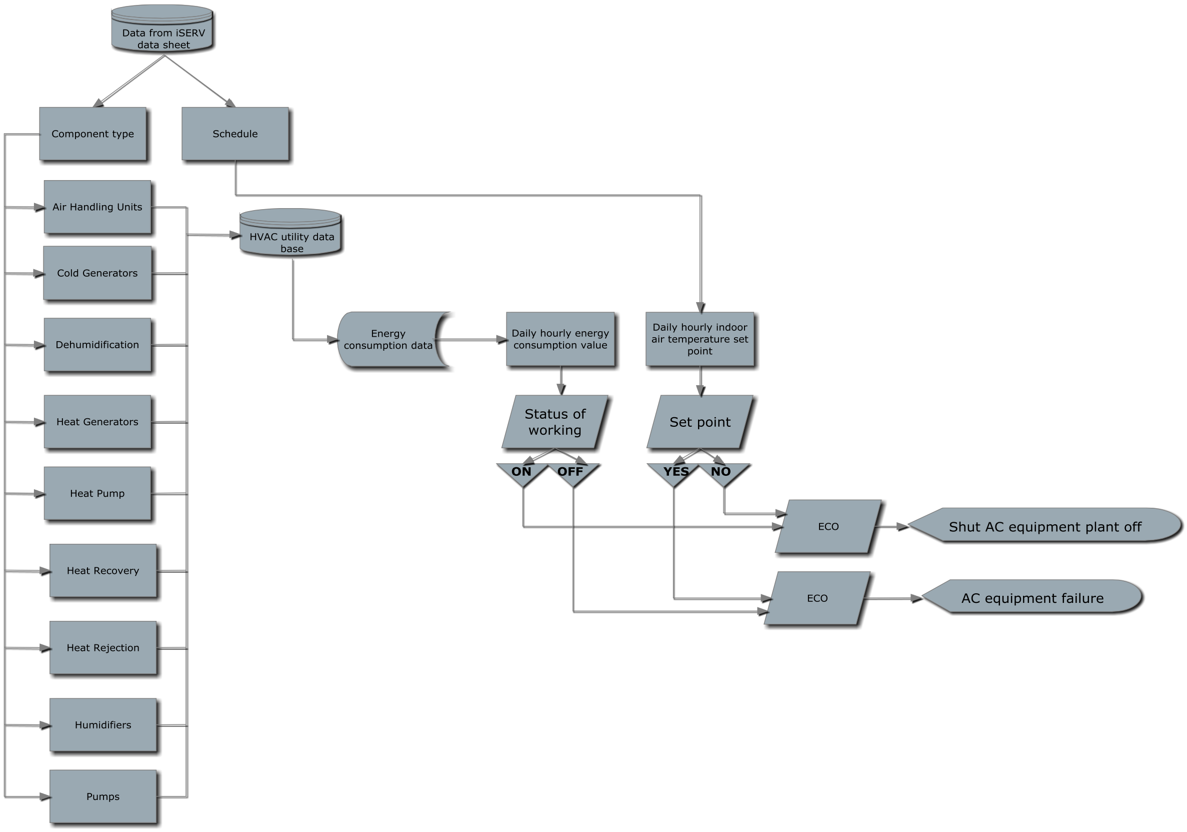
3.1.10.2 HVAC component data

- Nominal electric power input
- Nominal cooling capacity

3.1.10.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Number of operating hours

3.1.11 Algorithm for ECO detection



To reduce energy consumption of AC equipment's the algorithm checks the following:

- It`s happening that AC equipment's like chiller or chilled water pumps work outside the schedule of building. This ECO algorithm checks if AC equipment's work according to the building schedule, thereby preventing energy over-consumption.
- How AC equipment's contribute to the peak electricity load when they work properly in conjunction with the building schedule.

3.2 O2.3 Shut off auxiliaries when not required

3.2.1 Existing subsystems on which the ECO may apply

- Water-Based system, Air and water based system
- Electrical fan
- Electrical pumps

3.2.2 Considered actions

- You search for class efficiency of existing motor and you replace it with a motor which has a better class of efficiency
- To shut down any auxiliaries equipment (pump or fan) in case where there is no need for operation

3.2.3 Technical data to request to owner/manager or to find directly (manufacturer data)

You can search for motor's efficiency as a point (and precise load ratio at this point) or as a load/efficiency curve.

- Operating time of each motor

3.2.4 Technical observations to be made on site

BEM controls help to identify ratio of consumption of auxiliary equipment.

You can search on nameplate for rated power, rated current, rated voltage, rated frequency and speed and rated efficiency or class of efficiency.

- Pump efficiency
- Speed (rpm)
- Pump flow

3.2.5 Monitoring of existing situations

- Pump flow
- Initial flow rate
- Motor monitoring: RMS current mean of 3 phases, Root Mean Square (RMS) voltage mean line to line of 3 phases and power factor.
- Flow rate
- Difference between fan inlet total pressure and outlet total pressure
- Power consumption

3.2.6 Criterion for ECO applicability

You have to check if there is any need for pump or fan operation.

3.2.7 Recommendation for realization of ECO

You could examine measured electrical power of pumps and fans equipment for each day, weekend, month and year to find out if the measurements show any deviations and to find out if there is any need for intervention.

You could examine before:

- Fans and pumps are correctly controlled and mode of operation is set correctly.

You could shut down fans or pumps when to new improvement.

3.2.8 Additional support

3.2.9 Remarks

3.2.10 Input data required for ECO identification

3.2.10.1 HVAC sensor data

- Flow rate
- inlet pressure
- outlet pressure
- T - set point of indoor air temperature

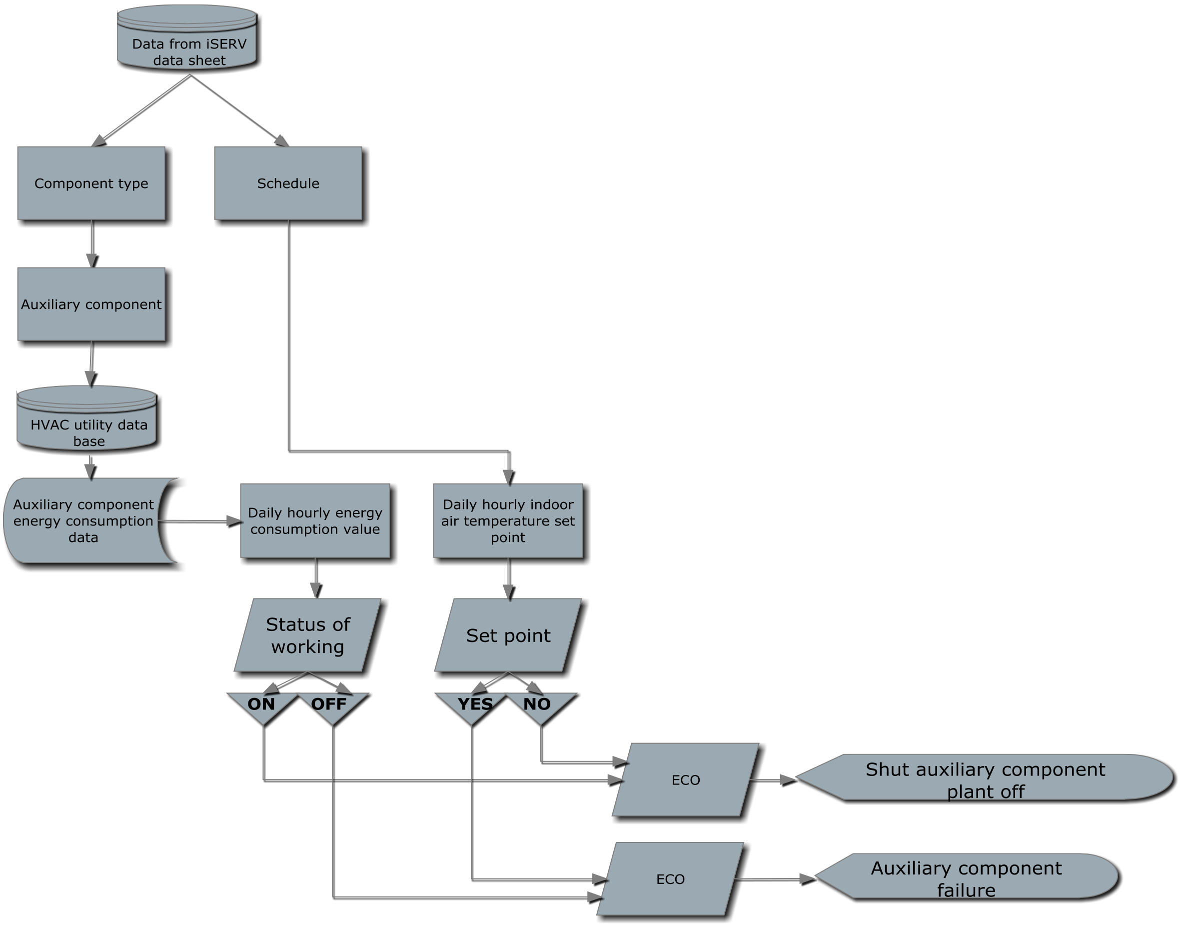
3.2.10.2 HVAC component data

- Nominal speed (rpm)
- Nominal flow rate
- Nominal electric power input

3.2.10.3 Schedule of Setpoint and Occupancy

- Occupancy schedule per zone
- Number of operating hours

3.2.11 Algorithm for ECO detection



3.3 O3.1 Shut chiller plant off when not required

3.3.1 Existing subsystems on which the ECO may apply

Water based system with incorporate multiple chillers and associated control.

3.3.2 Considered actions

To reduce exist energy consumption and to improve the efficient design and operation of the chilled water plant and air-conditioning system.

- To shut down chiller in case where there is no need for its operation.

3.3.3 Technical data to request to owner/manager or to find directly (manufacturer data)

You can search for rated power on nameplate, rated current, rated voltage, rated frequency and speed

- Number of functioning hours
- Refrigerant type of chiller
- Nominal consumption of chiller plant
- COP, EER, SEER, IPLV of chiller
- Data of water chiller
- Nominal electric power of chiller plant
- Temperature set point
- Pump efficiency
- Speed (rpm)
- Pump flow

3.3.4 Technical observations to be made on site

Description of water loop architecture

3.3.5 Monitoring of existing situations

- Measured temperature of inlet and outlet cold water
- Water flow rate
- Total operating time of the chiller plant
- Measured energy consumption of chiller plant
- Pump flow

3.3.6 Criterion for ECO applicability

- You could examine “frequency” of sequences and number of auxiliaries to control then you could justify the use of central control
- You should introduce a power limit to define a criteria.
- Criteria for subsystem 1: electrical motor of pump

We have to check if the existing pump is in the range of best efficient types.

- You could examine optimum arrangement balancing pump and chiller savings.

3.3.7 Recommendation for realization of ECO

With the use of variable speed drives and chiller plant optimization savings of 15 to 20% of the annual electricity cost can be achieved.

Variable speed drives. The ratio between " Speed/ flow " of the pump motor compared to energy consumption is the " Cubelaw " . That means if you reduce the Speed of the pump from 100% to 80% the energy consumption will be reduced from 100% to 52% .

You could shut off auxiliaries when not required according to new improvement.

You should train considered operators to have an energy-efficient O&M activities (ECO O1.3).

3.3.8 Additional support

3.3.9 References

http://www.itrademarket.com/PratamaJayaMandiri/1041660/chiller-plant-optimzation.htm

3.3.10 Input data required for ECO identification

3.3.10.1 HVAC sensor data

- Flow rate
- Temperature of inlet and outlet cold water
- T - set point of indoor air temperature

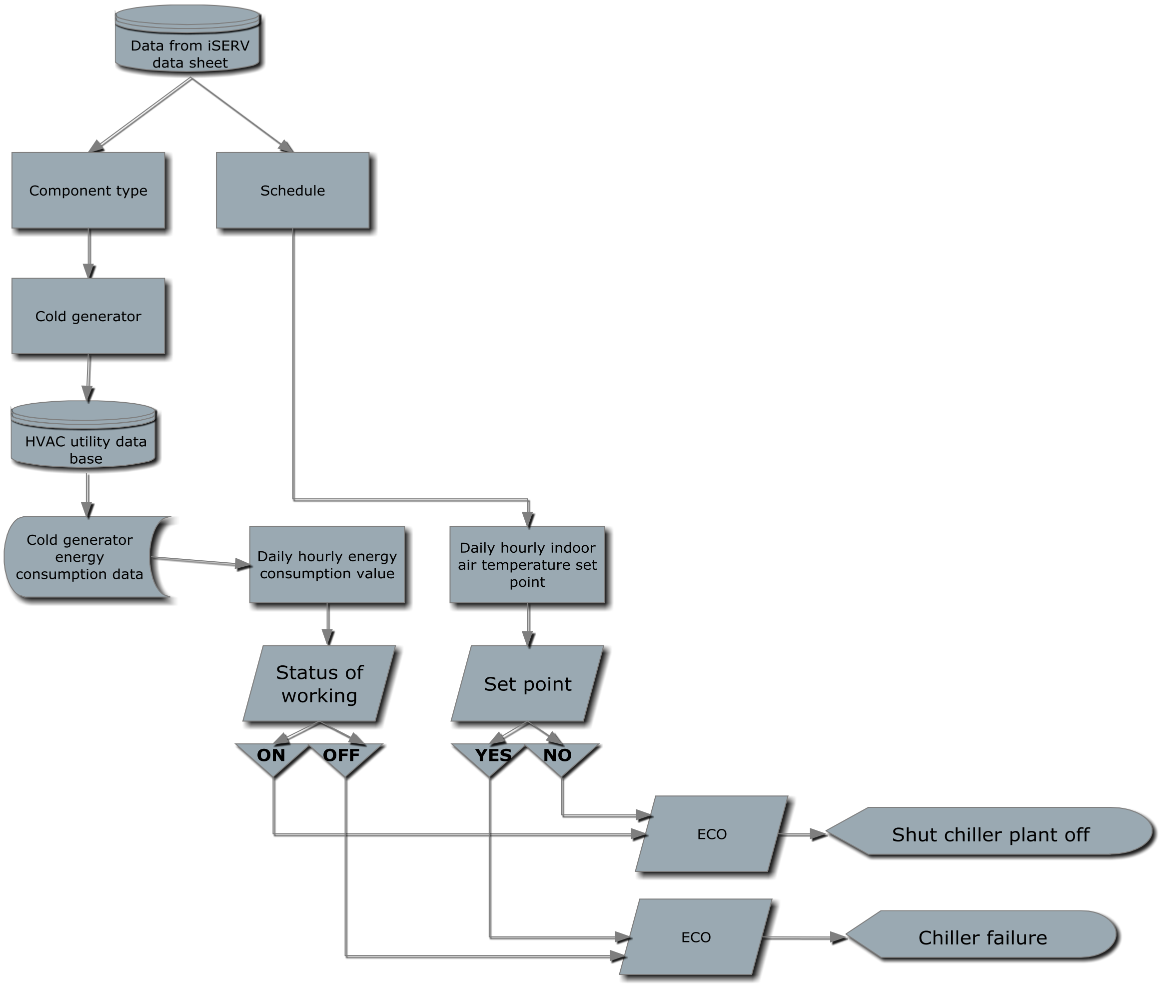
3.3.10.2 HVAC component data

- Rated frequency
- Nominal speed (rpm)
- Nominal flow rate
- Nominal electric power input
- Nominal cooling capacity
- Refrigerant type
- Cooling load
- (COP, EER, SEER, IPLV)

3.3.10.3 Schedule of Setpoint and Occupancy

- Number of operating hours
- Occupancy schedule per zone

3.3.11 Algorithm for ECO detection



To reduce energy consumption of cold generator (chiller) the algorithm checks the following:

- Algorithm checks if chiller works according to the building schedule, thereby preventing energy over-consumption.
- On peak load characteristics of building, algorithm can give recommendations for peak load reduction.

4 Priority 2

4.1 *P1.3 Modify management of HVAC system in order to enable sequencing heating and cooling*

4.1.1 Existing subsystems on which the ECO may apply

- Water-Based system
- Air and water based system

4.1.2 Considered action

To identify possible problem of interaction between heating and cooling.

4.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

To identify controller manufacturer and search for controller user's guide for heating and cooling control.

4.1.4 Technical observations to be made on site

4.1.5 Monitoring of existing situations

You could test sequence by forcing controls through controller interface and check position/operation of control valve, damper….

On figure 1, the temperature set points (T1 and T2) can be modified to sequence heating (1) and cooling (2).

4.1.6 Criterion for ECO applicability

The dead-band (see 1 on figure 1) could disappear when temperature measurement is not calibrate or not accurate. But it is possible; controller has not been correctly programmed. Figure 2 shows a problem of sequence.

You should estimate occurrences of simultaneous heating and cooling demand. You could consider temperature set points (and possible problems of measurement) and hourly outside temperature to identify interactions of cooling/heating.

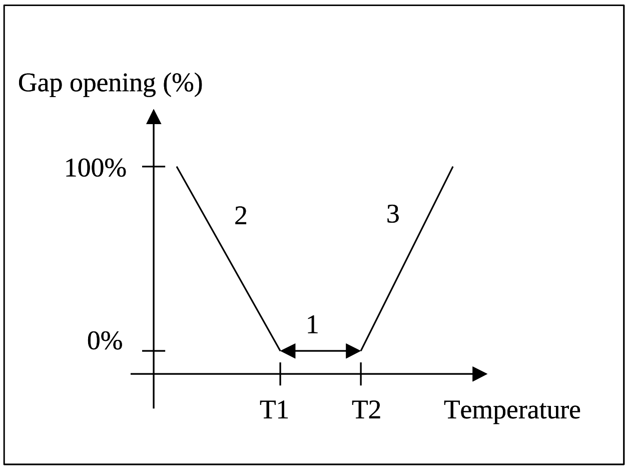


Figure 1

You can then maintain proper system set points ECO O2.4

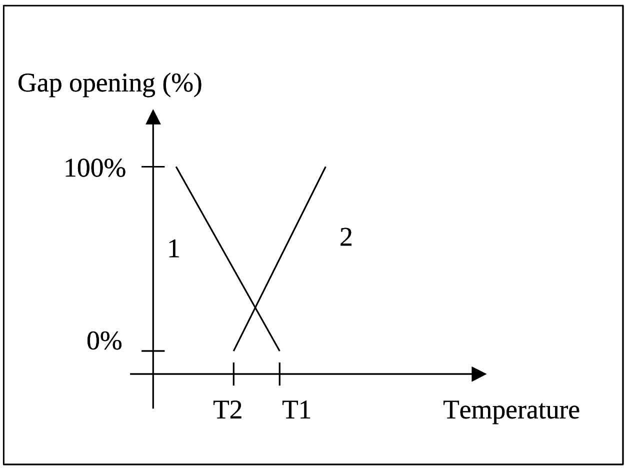


Figure 2

4.1.7 Recommendation for realization of ECO

You have to set a correct dead-band to sequence heating/cooling distribution. Heating (2) and cooling instruction (3) are separated by a dead-band (1) (see Figure 1).

4.1.8 Additional support

4.1.9 Remarks

4.1.10 Input data required for ECO identification

4.1.10.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling
- Temperature of inlet and outlet cold water
- T - set point of indoor air temperature

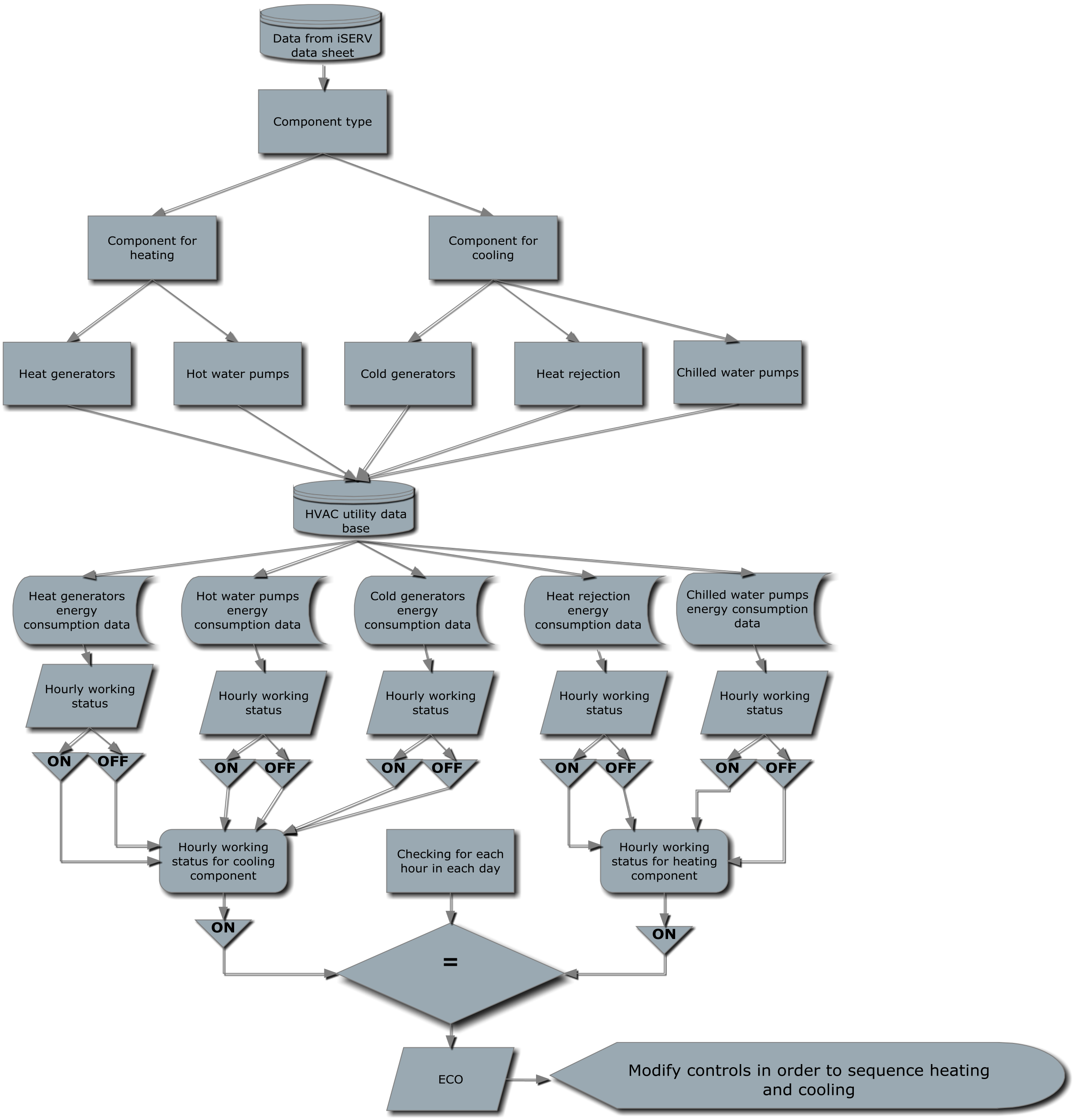
4.1.10.2 HVAC component data

- Nominal electric power input
- Nominal cooling capacity

4.1.10.3 Schedule of Setpoint and Occupancy

- Number of operating hours
- Occupancy schedule per zone

4.1.11 Algorithm for ECO detection



To reduce energy consumption of HVAC system the algorithm checks that components for heating and for cooling not operating at the same time.

4.2 P1.7 Reduce power consumption of auxiliary equipment

4.2.1 The following ECOs could be considered depending on type of auxiliaries:

- Pumps
- Fans

4.2.2 For fans you could consider here under options:

- Reduce motor size ECO P3.1
- Use the best Eurovent class of fan ECO P3.3
- Apply variable flow rate fan control ECO P3.6
- Consider applying demand-controlled ventilation ECO P3.10
- Replace duct when leaking ECO P3.12

4.2.3 For pumps you could consider hereunder options:

- Use the best class of pumps ECO P4.1
- Install variable volume pumping ECO P4.5

4.2.4 Maintenance operation

- Shut off auxiliaries when not required ECO O2.2

4.2.5 Reference:

Energy Consumption Characteristics of Commercial Building HVAC Systems Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation by Westphalen

4.2.6 Input data required for ECO identification

4.2.6.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- Condition of valve for heating
- Condition of valve for cooling
- Flow rate
- Temperature of inlet and outlet cold water
- Refrigerant fluid flow rate
- inlet pressure
- outlet pressure
- Pressure of refrigerant fluid
- Temperature of refrigerant fluid
- Temperature of refrigerant fluid at the outlet
- Temperature of cooling fluid at the inlet
- Temperature of cooling fluid at the outlet
- Temperature heat carrier fluid at the inlet
- Temperature heat carrier fluid at the outlet

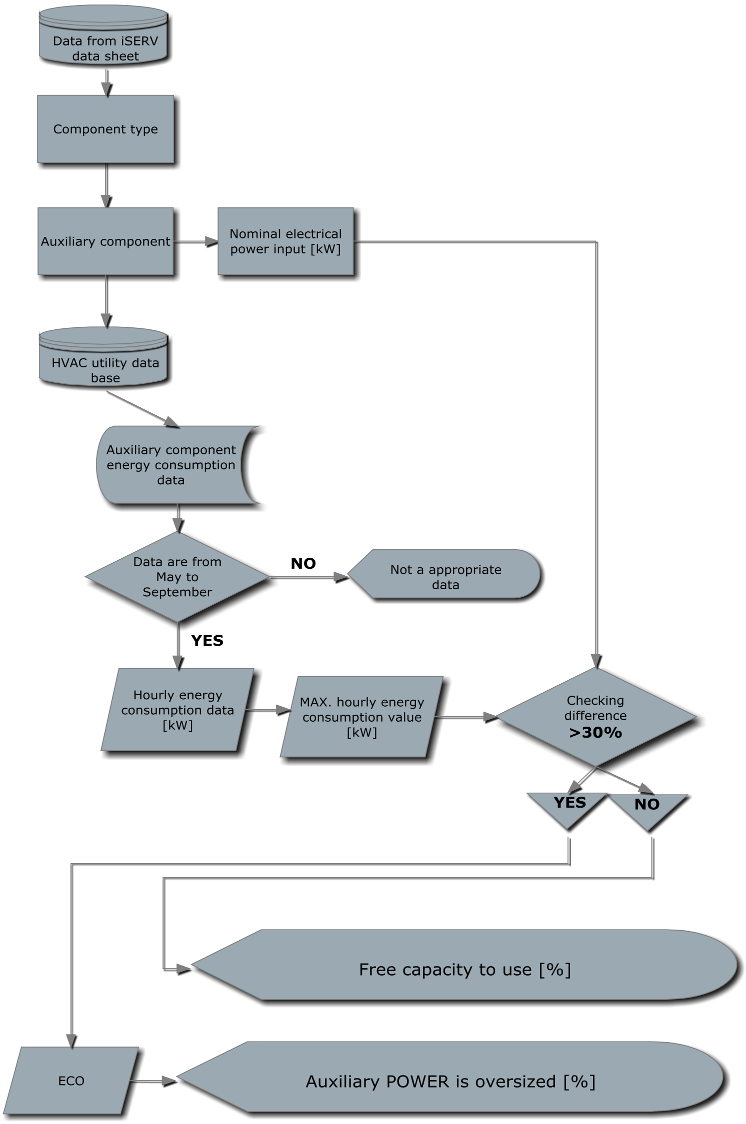
4.2.6.2 HVAC component data

- Nominal speed (rpm)
- Nominal flow rate
- Nominal electric power input

4.2.6.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Temperature regime
- Schedule of occupancy

4.2.7 Algorithm for ECO detection



To reduce energy consumption of pumps and fans the algorithm checks the following:

- Checks if HVAC component is oversized or in the best case that HVAC component has a free capacity that can be used, algorithm will alert the end-user with this ECO.

4.3 P2.3 Split the load among various chiller

4.3.1 Existing subsystems on which the ECO may apply

- Air-water based system
- All water based system

These subsystems distribute poorly the load.

You could consider also if:

- Chillers are in parallel with identical design, COP and part load characteristics: subsystem 1
- Different chillers are in parallel: subsystem 2
- Chillers are in series with identical design, COP and part load characteristics: subsystem 3
- Different chillers are in series: subsystem 4

4.3.2 Considered action

To sequence chiller to have a better overall efficiency

4.3.3 Technical data to request to owner/manager or to find directly (manufacturer data)

- Number of functioning hours for each compressor
- Refrigerant type of each chiller
- Nominal consumption of each compressor
- COP, EER, SEER, IPLV of each chiller

4.3.4 Technical observations to be made on site

Description of water loop architecture

4.3.5 Monitoring of existing situations

Power consumption of each chiller as a function of the leaving condenser water temperature and the chilled-water supply temperature.

4.3.6 Criterion for ECO applicability

4.3.6.1 *Criteria for chillers in parallel with identical design, COPs and part load characteristics (subsystem 1)*

$$Q_{opti} = \frac{Q_{load}}{\sum_{i=1}^{N} Q_{desi}} Q_{desi}$$

Where Q_{opti} is optimal loading of chiller i; Q_{load} is total chiller load; Q_{desi} is the cooling capacity of i th chiller at design conditions and N is the number of chillers operating.

The loading determine with previous equation gives a minimum of power consumption when the chillers are operating at loads greater than the point at which the maximum COP occurs.

4.3.6.2 *Criteria for different chillers in parallel (subsystem 2) (will be studied)*

You consider two type of control:

- To use individual chilled-water flow rate control (using a two-way valve) at equal chilled-water set points.
- To use different chilled-water set point

4.3.7 Recommendation for realization of ECO

Realization for chillers in parallel with identical design, COP and part load characteristics (subsystem 1). You could control individual chilled-water flow rate to achieve these load distribution

4.3.8 Additional support

References

ASHRAE Handbook-HVAC applications, 2007, 41.21 to 41.25

4.3.9 Input data required for ECO identification

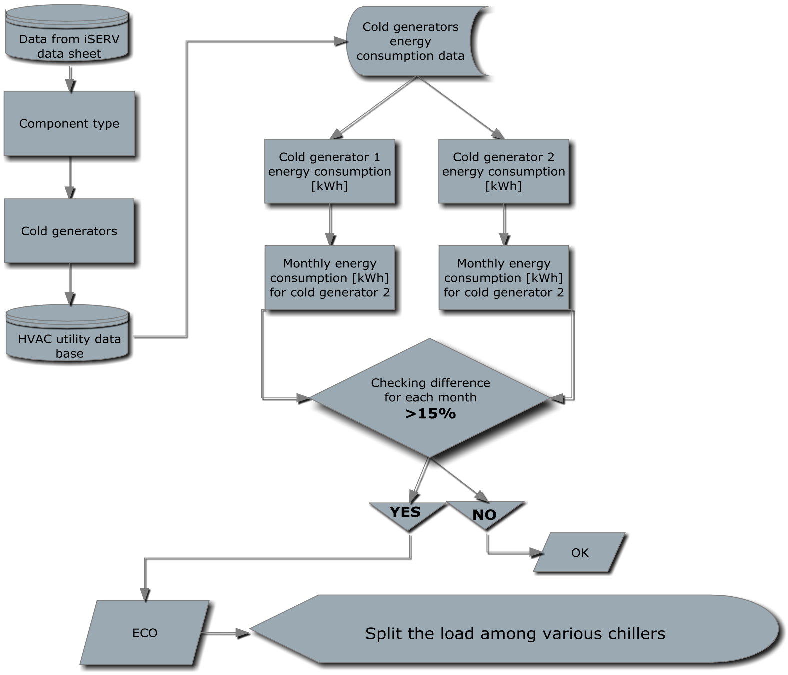
4.3.9.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- Condition of valve for heating
- Condition of valve for cooling
- Flow rate
- Temperature of inlet and outlet cold water
- Refrigerant fluid flow rate

4.3.9.2 HVAC component data

- Nominal electric power input

4.3.10 Algorithm for ECO detection



To reduce and to optimize energy consumption of chillers the algorithm check for solution to split the load among various chiller:

- Task of this algorithm is to check the difference in electricity energy consumption on the time of operation between individual chillers.

4.4 *P3.6 Apply variable flow rate fan control.*

4.4.1 Existing subsystems on which the ECO may apply

The subsystem is {fan}+{motor} or {motor-fan} when the flow is proven variable or potentially variable.

4.4.2 Considered actions:

4.4.2.1 Considered action 1

To install a variable speed drive control.

4.4.2.2 Considered action 2

To install a mechanical device for increases pressure losses.

4.4.2.3 Considered action 3

To install a mechanical device which increases pressure losses and a variable speed drive control.

4.4.2.4 Considered action 4

To install a mechanical device which increases pressure losses and a variable speed drive control at constant pressure.

4.4.3 Technical data to request to owner/manager or to find directly (manufacturer data)

If correct size of fan is installed, corresponding to maximum flow rate. So, P3.1 must be examined and if necessary must be applied first.

- You could search for fan's efficiency as a function of total or static or dynamic pressure curve.
- You could find the pressure specification of HVAC equipment to determine the best action.

4.4.4 Technical observations to be made on site

- Motor's nameplate speed, number of motor's poles and speed ratio of drive must be gathered to have the speed of the fan.
- To identify the possibility of variable speed drive operation (variable occupancy)

4.4.5 Monitoring of existing situations

- Motor monitoring: RMS current mean of 3 phases, RMS voltage mean line to line of 3 phases and power factor as a decimal.
- Flow rate
- Hours of occupation per zone.
- Motor's size must be examined to verify required power supply at maximum flow rate condition.(see P3.1)

4.4.6 Criterion for ECO applicability (to be tested)

The criterion of this ECO is to compare daily consumptions of fan at constant initial flow rate with daily consumptions of fan related with new control. A balance, between energy conservation and investments of setting up, must be made to determine feasibility.

4.4.6.1 Criterion of action 1 (to be tested): to install a variable speed drive control

The relative flow rate, as defined by ratio of minimum flow rate and maximum flow rate, is computed between 20% and 85%.

4.4.6.2 Criterion of action 2 (to be tested): to install a mechanical device which increases pressure losses.

The relative flow rate, as defined by ratio of minimum flow rate and maximum flow rate, is computed between 85% and 95%.

4.4.6.3 *Criterion of action 3: to install a mechanical device which increases pressure losses and a variable speed drive control.*

To be studied.

4.4.6.4 *Criterion of action 4: To install a mechanical device which increases pressure losses and a variable speed drive control at constant pressure.*

To be studied.

4.4.7 Recommendation for realization of the opportunity

4.4.7.1 *Recommendation for realization of action 1: to install a variable speed drive control*

The new motor's speed must be computed as a function of initial speed, initial flow rate, selected variable flow rate and scheduled distribution. So, program control law can be programmed with motor's speed as a function of occupancy schedule.

4.4.7.2 *Recommendation for realization of action 2: to install a mechanical device for increases pressure losses.*

Pressure losses control must be achieved desired flow rate.

4.4.8 Remarks

It would be assumed that overall efficiency is the same at different fan's speed, while hydraulic efficiency is a constant (similitude rules) and motor's efficiency is not (see Beyond the affinity laws, Engineered Systems, August 2004 by Tumin Chan)

4.4.9 Input data required for ECO identification

4.4.9.1 *HVAC sensor data*

- Flow rate

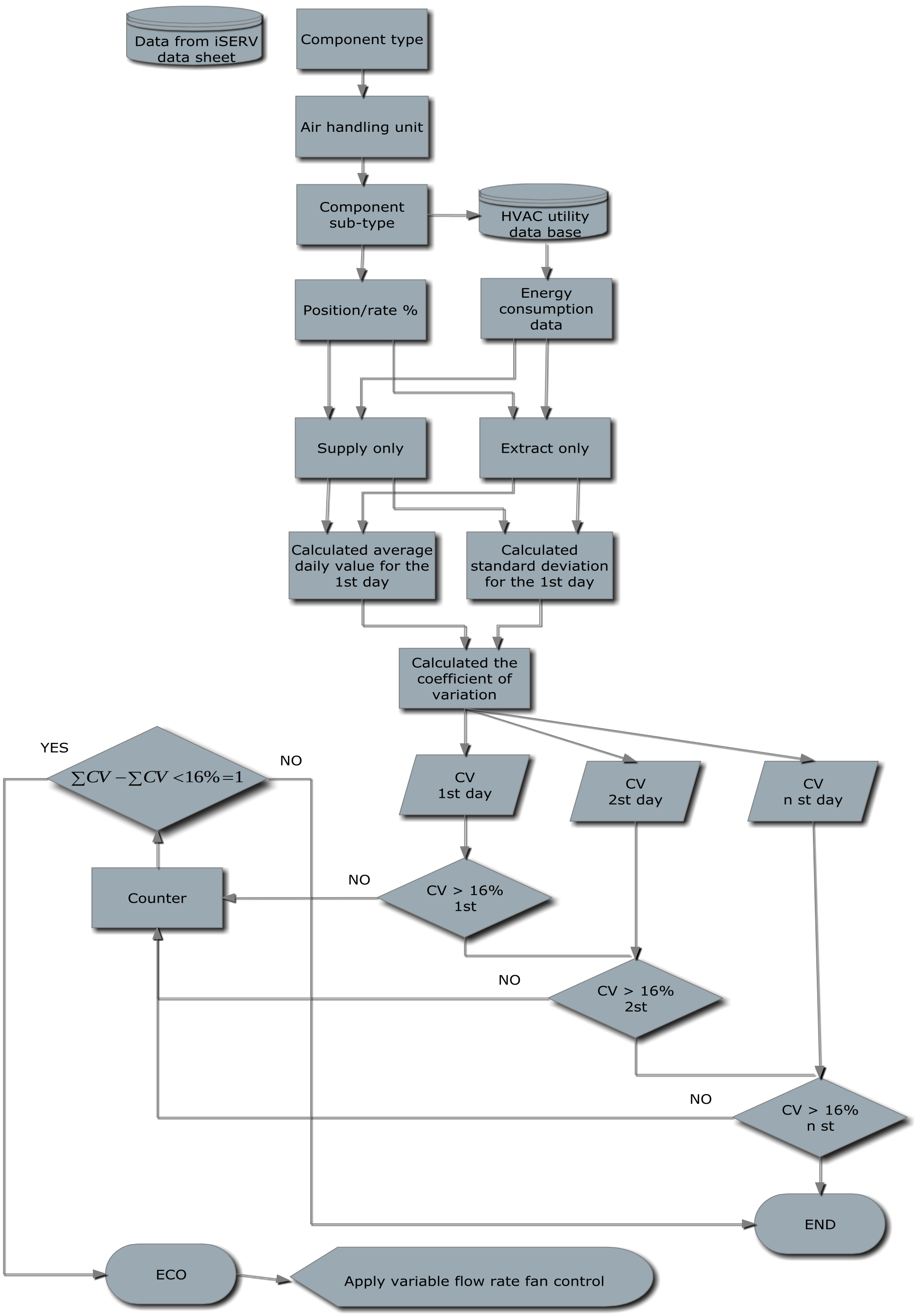
4.4.9.2 *HVAC component data*

- Pressure specification of HVAC equipment

4.4.9.3 *Schedule of Setpoint and Occupancy*

- Number of operating hours

4.4.10 Algorithm for ECO detection



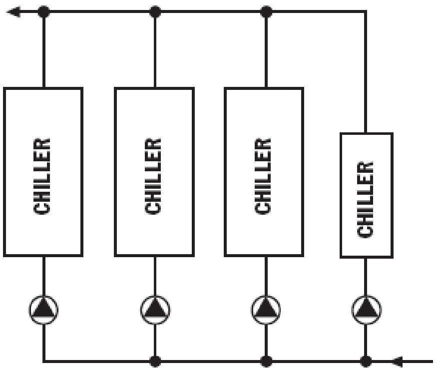
To reduce and to optimize energy consumption of fans the algorithm check for solution to apply variable speed drive control into HVAC control system:

- The criterion of this algorithm is to calculate the CV (coefficient of variation) of working fans for the whole day and for all days of the week. A CV value smaller than 16% for all days of the week indicates the invariability in the operation of fans, i.e. the possibility for installing variable speed drive control.

4.5 P4.5 Install variable flow rate pumping

4.5.1 Existing subsystems on which the ECO may apply

- Subsystem 1: Pumps which distribute cold water of staged chillers for variable cooling production and which don't operate at variable water flow rate (possible?)
- Subsystem 2: Pumps which distribute cold water of multiple chillers for variable cooling production.



4.5.2 Considered actions

4.5.2.1 Considered action 1

To control the pump motor with a variable speed drive (VSD) strategy=>1

4.5.2.2 Considered action 2

To replace existing pump(s) with a variable volume pumping at same design conditions

4.5.2.3 Considered action 3

To replace existing pump(s) with a bigger variable volume pumping at same design condition

4.5.2.4 Considered action 4

To replace existing pumps with a bigger pump controlled by VSD

4.5.3 Technical data to request to owner/manager or to find directly (manufacturer data)

You can search for motor's efficiency as a point (and precise load ratio at this point) or as a load/efficiency curve.

4.5.4 Technical observations to be made on site

You can search for on nameplate rated power, rated current, rated voltage, rated frequency and speed. Common monitoring of existing situations

- Initial flow rate
- Motor monitoring: RMS current mean of 3 phases, Root Mean Square(RMS) voltage mean line to line of 3 phases and power factor.
- Occupancy schedule per zone.
- Motor's size must be examined to verify required power supply at maximum flow rate condition.(see P4.1)

4.5.5 Specific monitoring of existing situations

4.5.5.1 {Subsystem 1} monitoring

No specific monitoring suggested

4.5.5.2 <u>{Subsystem 2} monitoring</u>

Output/input frequency of power supply converter

4.5.5.3 <u>{Subsystem 3} monitoring</u>

Output/input voltage of power supply converter

4.5.6 Criterion for ECO applicability

Depending on subsystem type you can examine the following actions:

	Subsystem 1 Staged chiller	Subsystem 2 Parallel chiller
action 1	ok	
action 2	ok	
action 3		ok
action 4		ok

4.5.6.1 <u>Criterion for {subsystem 1}</u>

You must have

The criterion of an oversized motor is based on load ratio, which is the ratio between the measured input power and the power required when the motor operates at rated power. Indeed, most electric motors are designed to run between 50% and 100% of rated load. A motor efficiency decreases dramatically below 50% load.

The criterion is when load measure ratio is under 70% then action 1(a replacement of the motor) must be done.

If load measure ratio is between 70% and 95% action 2 must be done.

4.5.6.2 <u>Criterion for {subsystem 2}</u>

The criterion is when load measure ratio is under 30% then action 1(a replacement of the motor) must be done.

4.5.6.3 <u>Criterion for {subsystem 3}</u>

The criterion is when load measure ratio is under 40% then action 1(a replacement of the motor) must be done.

4.5.7 Recommendation for realization of ECO

You could control volume pumping in order to match cooling needs (by a control of input/output temperature of cooled water.

4.5.8 Additional support

4.5.8.1 <u>Equations:</u>

- **Eq1** $load = (\Omega_S - \Omega)/(\Omega_S - \Omega_N)$

where $\Omega_S = 60 * f / p$

$load = P_m / P_N$

p number of pole couple

f frequency of motor supply power

Ω_S synchronous speed in rpm

Ω_N nameplate speed

P_m measured input three phase power

P_N nameplate power.

- **Eq2** $$load = \frac{(\Omega_{SC} - \Omega_C)}{\Omega_{SC}} \frac{\Omega_N}{(\Omega_{SO} - \Omega_C)}$$

Where Ω_{SC} current synchronous speed in rpm (calculate with output frequency of converter)

Ω_N nameplate speed in rpm

Ω_{SO} original synchronous speed in rpm

4.5.9 References

[1] Determining motor efficiency and load, Motor challenge program US department of energy.

4.5.10 Input data required for ECO identification

4.5.10.1 HVAC sensor data

- Flow rate

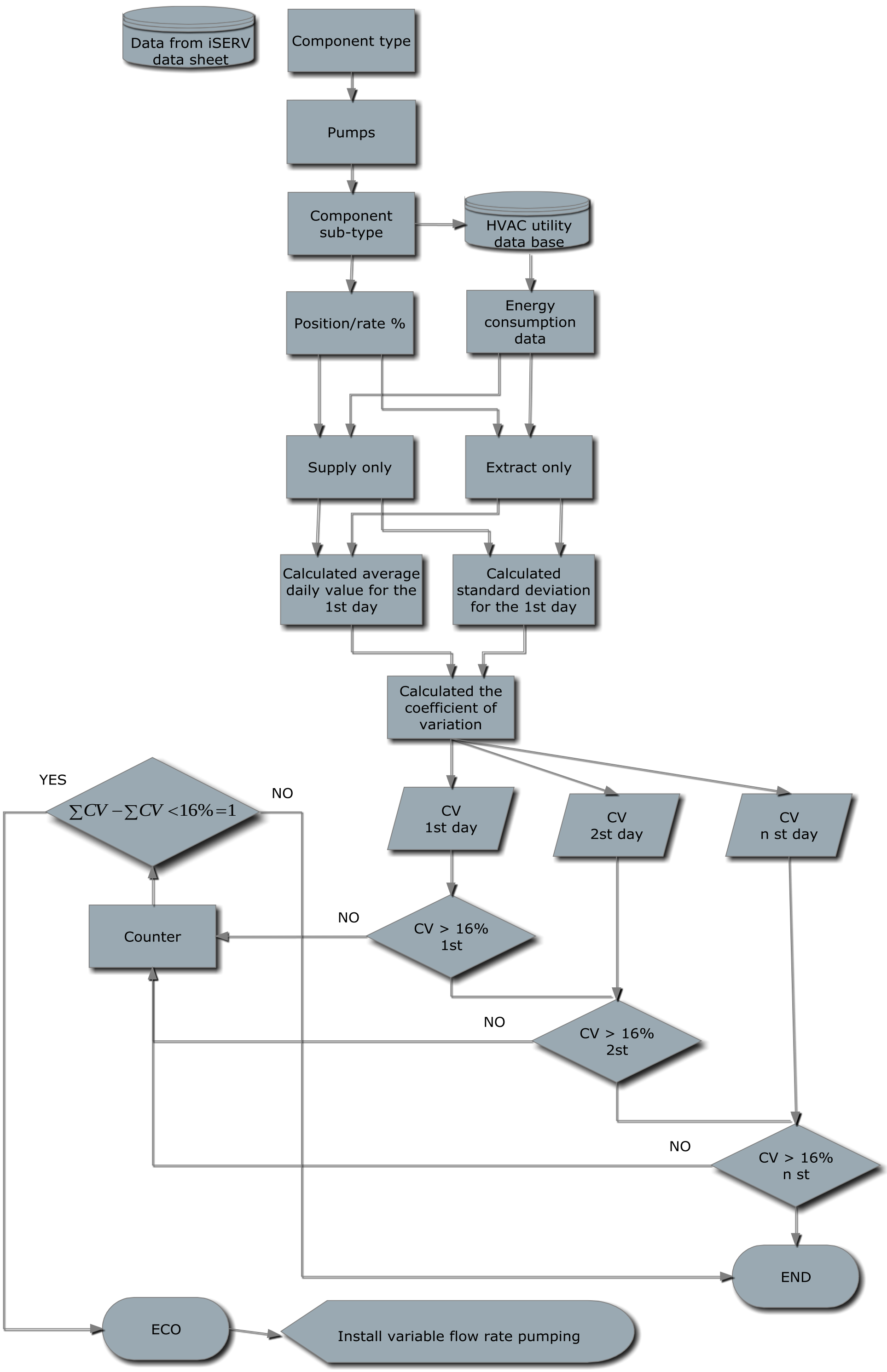
4.5.10.2 HVAC component data

- Nominal flow rate
- Nominal electric power input

4.5.10.3 Schedule of Setpoint and Occupancy

- Occupancy schedule per zone
- Number of operating hours
- Schedule of occupancy

4.5.11 Algorithm for ECO detection



5 Priority 3

5.1 P2.5 Improve central chiller / refrigeration control

5.1.1 Existing subsystems on which the ECO may apply

Water based system with incorporate multiple chillers and associated control.

5.1.2 Considered action

You could install / replace central controller in order to control new possibilities of sequences.

5.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

You could examine possibilities (not used) of control by using existing controller.

5.1.4 Technical observations to be made on site

Description of water loop architecture

5.1.5 Monitoring of existing situations

5.1.6 Criterion for ECO applicability

You could examine "frequency" of sequences and number of auxiliaries to control then you could justify the use of central control

You should introduce a power limit to define a criteria.

You could control centrally if 3 or more of the following ECOs have been feasible:

- Sequence operation of multiple unit ECO O3.2
- Operate chillers in series and parallel ECO O3.3
- Track and optimize chillers or compressor in series or parallel ECO O3.4
- Raise chilled water temperature and suction gas pressure ECO O3.8
- Spilt the load among various chiller ECO P2.3
- Repipe chillers / compressors in series or parallel ECO P2.4

5.1.7 Recommendation for realization of ECO

You could stop auxiliaries (ECO O2.3) according to new improvement.

You should train considered operators to have an energy-efficient O&M activities (ECO O1.3)

5.1.8 Additional support

5.1.9 Remarks

5.1.10 Input data required for ECO identification

5.1.10.1 <u>HVAC sensor data</u>

- T - outdoor air temperature
- T - indoor air temperature

5.1.10.2 <u>HVAC component data</u>

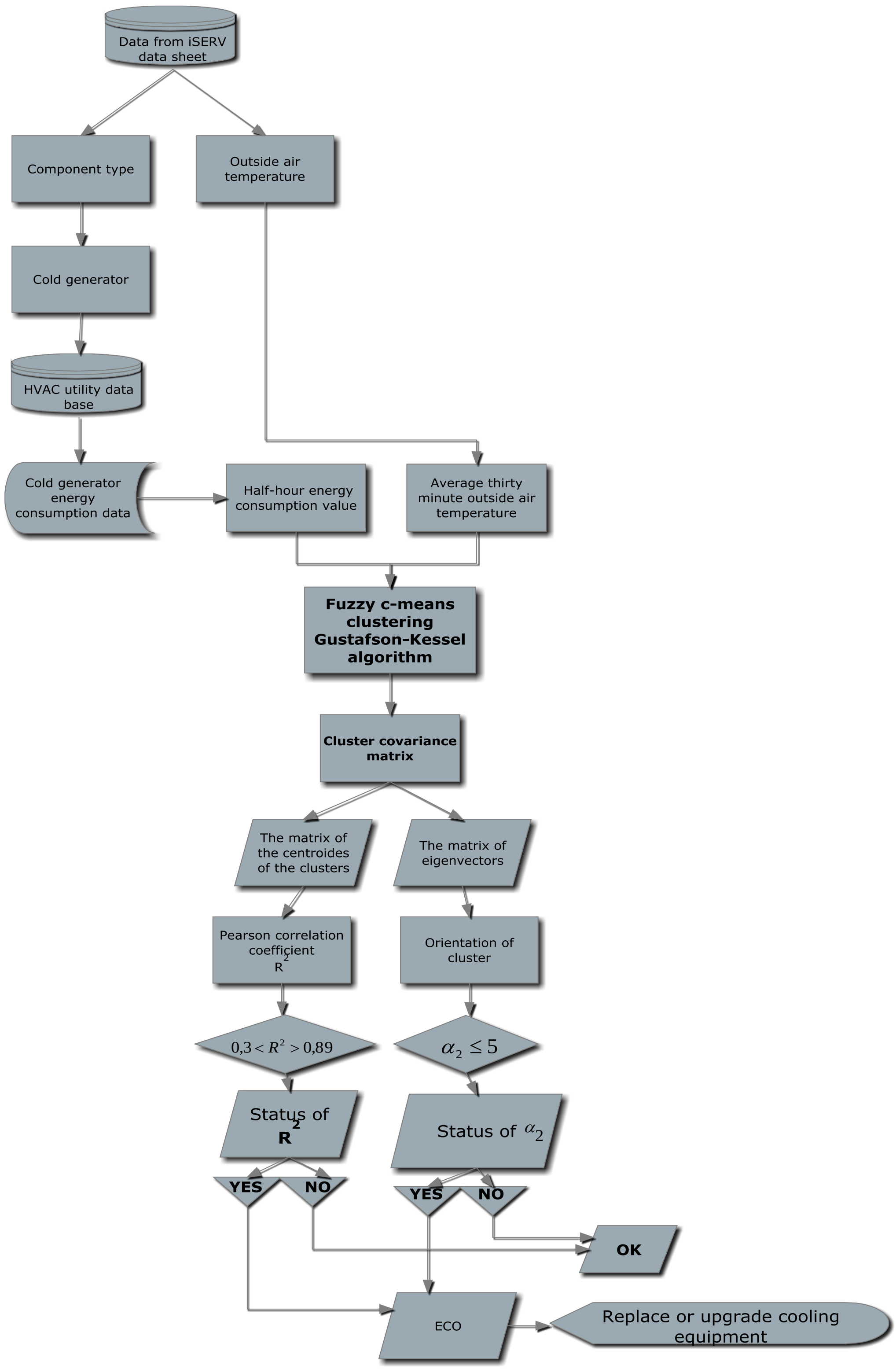
- Nominal electric power input
- Nominal cooling capacity

5.1.10.3 <u>Schedule of Setpoint and Occupancy</u>

- T - set point of indoor air temperature

- Number of operating hours

5.1.11 Algorithm for ECO detection



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5.2 P3.7 Consider conversion to VAV

5.2.1 Existing subsystems on which the ECO may apply

The subsystems are heating, ventilating and air conditioning HVAC system.

The subsystem is {fan}+{motor} or {motor-fan} when the flow is proven variable or potentially variable.

5.2.2 Considered actions

The simplest VAV system incorporates one supply duct that, when in cooling mode, distributes approximately 13 °C supply air. Because the supply air temperature, in this simplest of VAV systems, is constant, the air flow rate must vary to meet the rising and falling heat gains or losses within the thermal zone served.

- You could also generate the possibility to adopt variable speed control strategy (ECO P1.5) according fan and pump control.
- Apply variable flow rate fan control (ECO P3.6).
- Implementation of variable flow rate control strategy (ECO P1.5).
- Install a mechanical device which increases pressure losses and a variable speed drive control.
- Install a mechanical device which increases pressure losses and variable drive control at constant pressure.
- To control the pump motor with a variable speed drive VSD.
- To replace existing pumps with a variable volume pumping at same design conditions.
- To replace existing pumps with a bigger pump controlled by VSD.

5.2.3 Technical data to request to owner/manager or to find directly (manufacturer data)

The fan capacity control, especially with modern electronic variable speed drives, reduces the energy consumed by fans which can be a substantial part of the total cooling energy requirements of a building. Dehumidification is greater with VAV systems than it is with constant volume system which modulates the discharge air temperature to attain part load cooling capacity.

The air blower's flow rate is variable. For a single VAV air handler that serves multiple thermal zones, the flow rate to each zone must be varied as well.

- Fan Speed(rpm)
- Pump flow
- You could search for fan’s and pump`s efficiency as a function of total or static or dynamic pressure curve.
- You could find the pressure specification of HVAC equipment to determine the best action.

5.2.4 Technical observations to be on site

- Motor’s nameplate speed, number of motor’s poles and speed ratio of drive must be gathered to have the speed of the fan.
- To identify the possibility of variable speed drive operation (variable occupancy)

5.2.5 Monitoring of existing situations

- Motor monitoring: RMS current mean of 3 phases, RMS voltage mean line to line of 3 phases and power factor as a decimal.
- Initial flow rate
- Hours of occupation per zone.
- Motor’s size must be examined to verify required power supply at maximum flow rate condition.(see P3.1)

5.2.6 Criterion for ECO applicability

The criterion of this ECO is to compare daily consumptions of fan at constant initial flow rate with daily consumptions of fan related with new control. A balance, between energy conservation and investments of setting up, must be made to determine feasibility.

5.2.6.1 Install a variable speed drive control (The relative flow rate, as defined by ratio of minimum flow rate and maximum flow rate, is computed between 20% and 85%)

5.2.6.2 Install a mechanical device which increases pressure losses.

5.2.7 Recommendation for realization of ECO

Cooling and heating load calculations are made for every module or zone in the building so that individual maxima and simultaneous maximum cooling/ heating requirements and air quantities can be established.

The design temperature of supply air at the terminal (allowing for all normally calculated extraneous gains such as fan heat and duct wall heat pick-up) is arrived at by conventional psychometric calculations.

The criterion of an oversized motor is based on load ratio, which is the ratio between the measured input power and the power required when the motor operates at rated power. Indeed, most electric motors are designed to run between 50% and 100% of rated load. A motor efficiency decreases dramatically below 50% load.

The criterion is when load measure ratio is under 70% then action 1(a replacement of the motor) must be done.

If load measure ratio is between 70% and 95% action 2 must be done.

5.2.7.1 Recommendation for realization of action 1: to install a variable speed drive control

The new motor's speed must be computed as a function of initial speed, initial flow rate, selected variable flow rate and scheduled distribution. So, program control law can be programmed with motor's speed as a function of occupancy schedule.

5.2.7.2 Recommendation for realization of action 2: to install a mechanical device which increases pressure losses.

Pressure losses control must be achieved desired flow rate.

5.2.7.3 Recommendation for realization of action 3:

You could control volume pumping in order to match cooling needs (by a control of input/output temperature of cooled water.

5.2.8 Additional support

5.2.9 Remarks

It would be assumed that overall efficiency is the same at different fan's speed, while hydraulic efficiency is a constant (similitude rules) and motor's efficiency is not (see Beyond the affinity laws, Engineered Systems, August 2004 by Tumin Chan)

5.2.10 Input data required for ECO identification

5.2.10.1 HVAC sensor data

- Flow rate

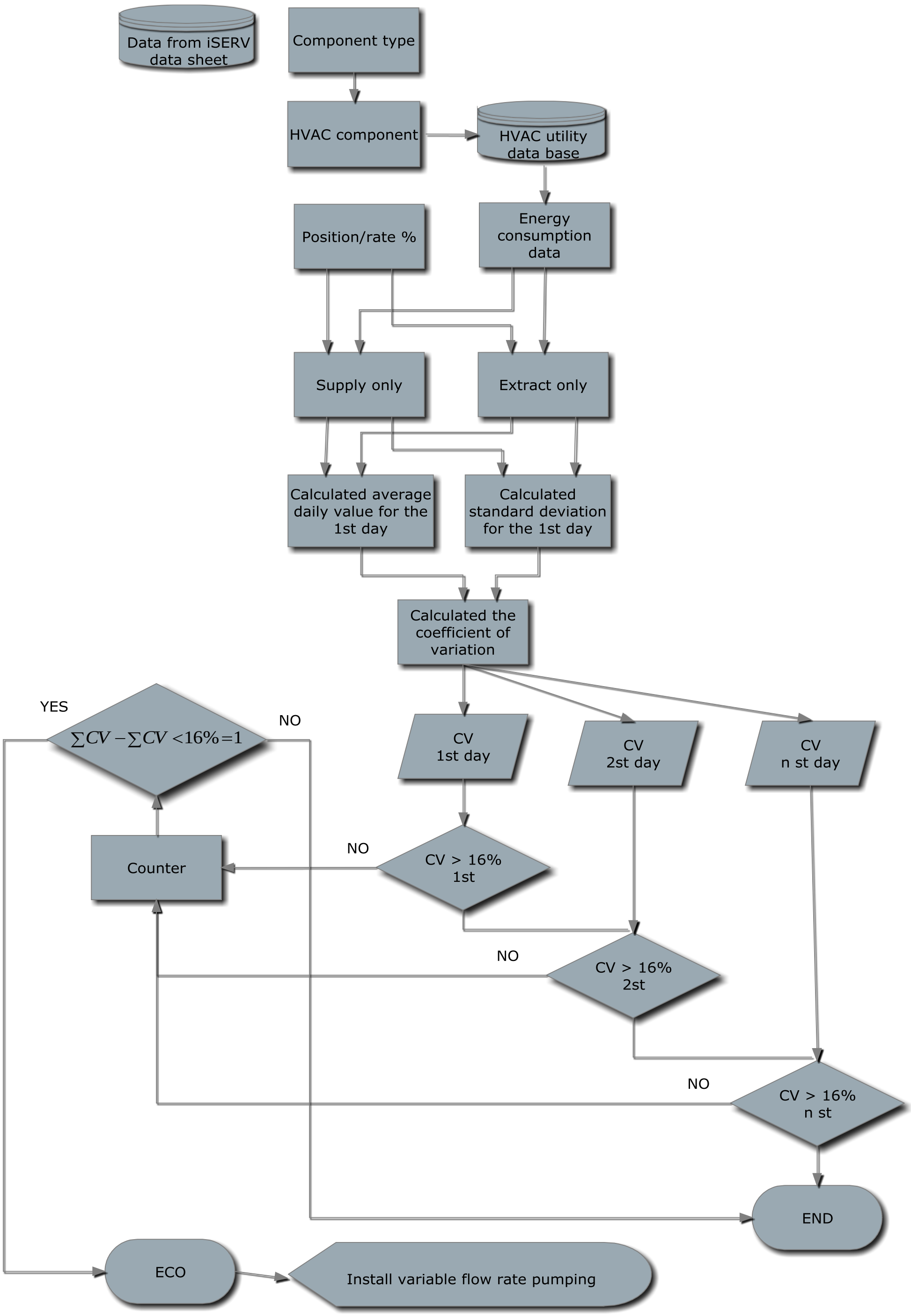
5.2.10.2 HVAC component data

- Nominal speed (rpm)
- Nominal flow rate
- Pressure specification of HVAC equipment

5.2.10.3 <u>Schedule of Setpoint and Occupancy</u>

- Number of operating hours

5.2.11 Algorithm for ECO detection



To reduce and to optimize energy consumption of pumps and fans the algorithm check for solution to apply variable speed drive control into HVAC control system:

- The criterion of this algorithm is to calculate the CV (coefficient of variation) of working pumps and fans for the whole day and for all days of the week. A CV value smaller than 16% for all days of the week indicates the invariability in the operation of HVAC system components, i.e. the possibility for installing variable speed drive control.

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5.3 O4.2 Perform night time ventilation

5.3.1 Existing subsystems on which the ECO may apply

- Air and water based system

5.3.2 Considered actions

The basic concept of night-time ventilation involves cooling the building structure overnight in order to provide a heat sink during the occupancy period. As this requires a sufficiently high temperature difference between the ambient air and the building structure, the efficiency of night cooling is highly sensitive to climatic conditions and hence also to climate warming.

5.3.3 Technical data to request to owner/manager or to find directly (manufacturer data)

Technical documentation of building.

5.3.4 Technical observations to be made on site

You have to check the condition and possibility for night ventilation.

5.3.5 Monitoring of existing situations

- Initial flow rate
- Hours of occupation per zone
- T - outdoor air temperature
- T - indoor air temperature

5.3.6 Criterion for ECO applicability

For night ventilative cooling, no lower limit need be placed on outdoor air temperatures but the humidity limit will be maintained to avoid moisture-related problems in building materials and furnishings. Thus, the Night Ventilative Cooling Criteria are:

$T_0 \leq T_{i-csp} = 26^0 C$ and $T_{o-dp} \leq 17^0 C$

When daytime outdoor temperatures exceed Ti-csp (indoor cooling set point), direct ventilation is no longer useful.

5.3.7 Recommendation for realization of ECO

Cooling the building's thermal mass with outdoor air during the previous night may be able to

offset daytime internal gains, however, if the outdoor air temperature drops below Ti-csp during the night. When this is possible, the heat transfer rate at which energy may be removed from the buildings thermal mass q_{night} approaches, in the limit for a very massive building:

$$q_{night} \approx \dot{m} C_p \left(T_{i-csp} - T_o \right) when\, T_o < T_{i-csp}$$

The total energy removed from the building's thermal mass during the evening may then be

used to offset internal gains on the subsequent workday. The average internal gain that may

be offset is equal to the integral of the night removal rate divided by the workday time period:

$$\bar{q}_{cool} = \int_{nighttime} \frac{q_{night}}{\Delta t}$$

5.3.8 Additional support

5.3.9 References

ASHRAE (1997a). WYEC2: Weather Year for Energy Calculations 2. ASHRAE.

ASHRAE (1997b) 1997 ASHRAE Handbook – Fundamentals. SI Edition ed., ASHRAE.

ASHRAE (1999), ASHRAE Standard 62-99: Ventilation for Acceptable Indoor Air Quality,

ASHRAE. Axley, J.W. (2001). Application of Natural Ventilation for U.S. Commercial Buildings – Climate Suitability, Design Strategies & Methods, and Modeling Studies. GCR-01-820, National Institute of Standards and Technology.

Bourgeois, D., A. Potvin, and F. Haghighat. (2000) Hybrid Ventilation Of Canadian Non-Domestic Buildings : A Procedure For Assessing IAQ, Comfort And Energy Conservation. in RoomVent 2000. University of Reading: Elsevier.

Emmerich, S.J., W.S. Dols, and J.W. Axley. (2001) Natural Ventilation Review and Plan for Design and Analysis Tools. NISTIR 6781, National Institute of Standards and Technology.

Levermore, G.J., A.M. Jones, and A.J. Wright (2000). Simulation of a Naturally Ventilated Building at Different Locations. ASHRAE Transactions, Vol. 106 (Part 2).

5.3.10 Input data required for ECO identification

5.3.10.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- Initial flow rate
- Nominal electric power input

5.3.10.2 HVAC component data

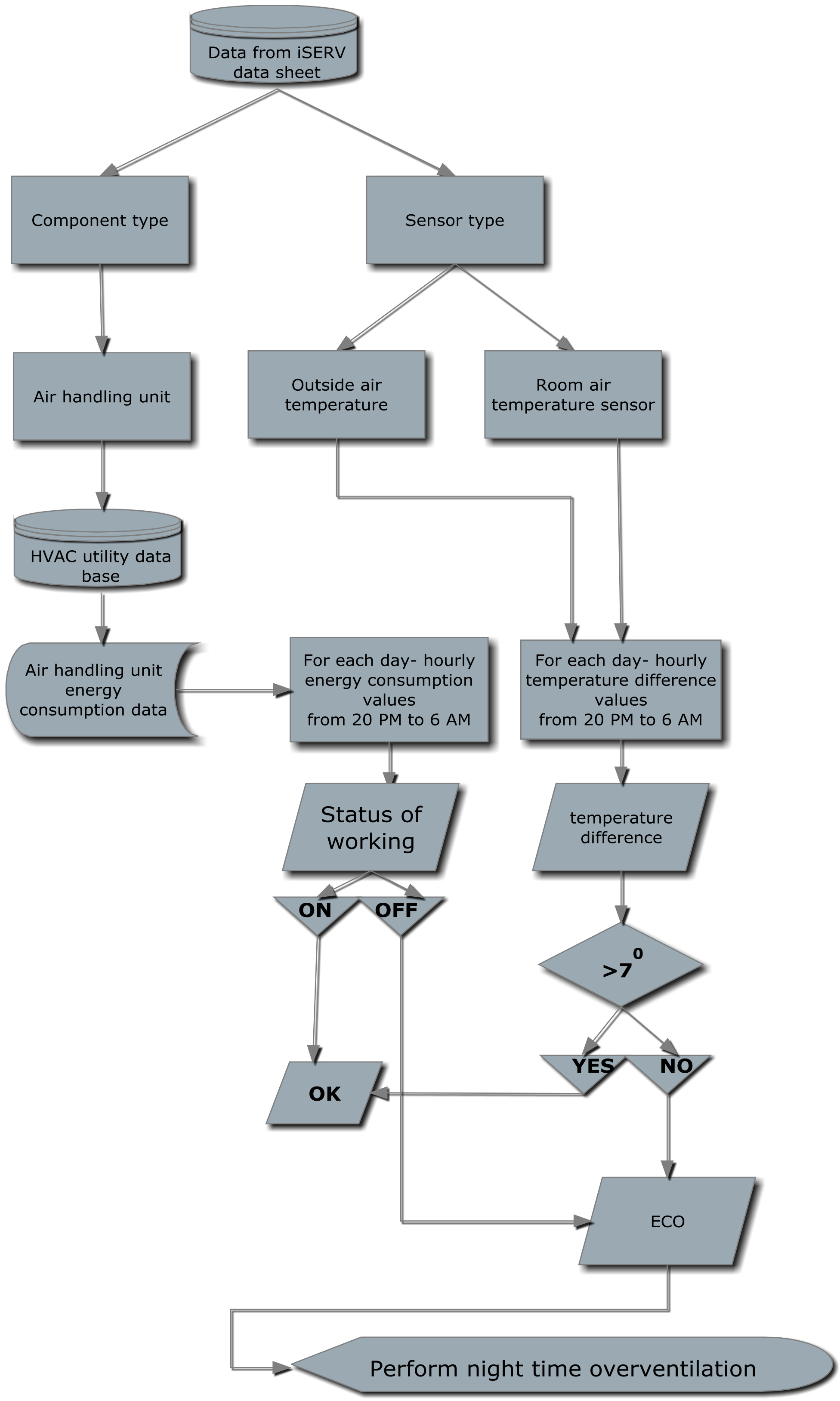
- Nominal flow rate
- Pressure specification of HVAC equipment

5.3.10.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Number of operating hours
- Hours of occupation per zone

5.3.11 Algorithm for ECO detection

To reduce exist energy consumption and to improve the efficient design and operation of the air-conditioning system.



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6 Priority 4

6.1 *P2.2 Reduce compressor power or fit a smaller compressor*

6.1.1 Existing subsystems on which the ECO may apply

If you have a separated compressor from evaporator and condenser; in addition the compressor can be a

- Single staged compressor
- Staged compressor

6.1.2 Considered actions

- To reduce motor size by using same methods as fan see ECO P3.1 (e.g. to reduce speed of motor's compressor)
- To replace compressor can generate some difficulties to match with new compressor requirement (e.g. oil).

6.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

- Compressor oil type
- Refrigerant type

You could estimate

- cooling load
- COP, EER, SEER, IPLV of cooling production

6.1.4 Technical observations to be made on site

6.1.5 Monitoring of existing situations

You could use a running meter to determine running time (hours) and number of start for a time elapsed.

6.1.6 Criterion for ECO applicability

You could estimate mean number of start per hour. You could compare estimated production and estimated demand.

6.1.7 Recommendation for realization of ECO

After compressor change, you could also change temperature set point/pressure to optimise heat exchange of condenser / evaporator (ECO O3.7 O3.8 O3.9)

6.1.8 Additional support

6.1.9 Remarks

6.1.10 Input data required for ECO identification

6.1.10.1 <u>HVAC sensor data</u>

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling

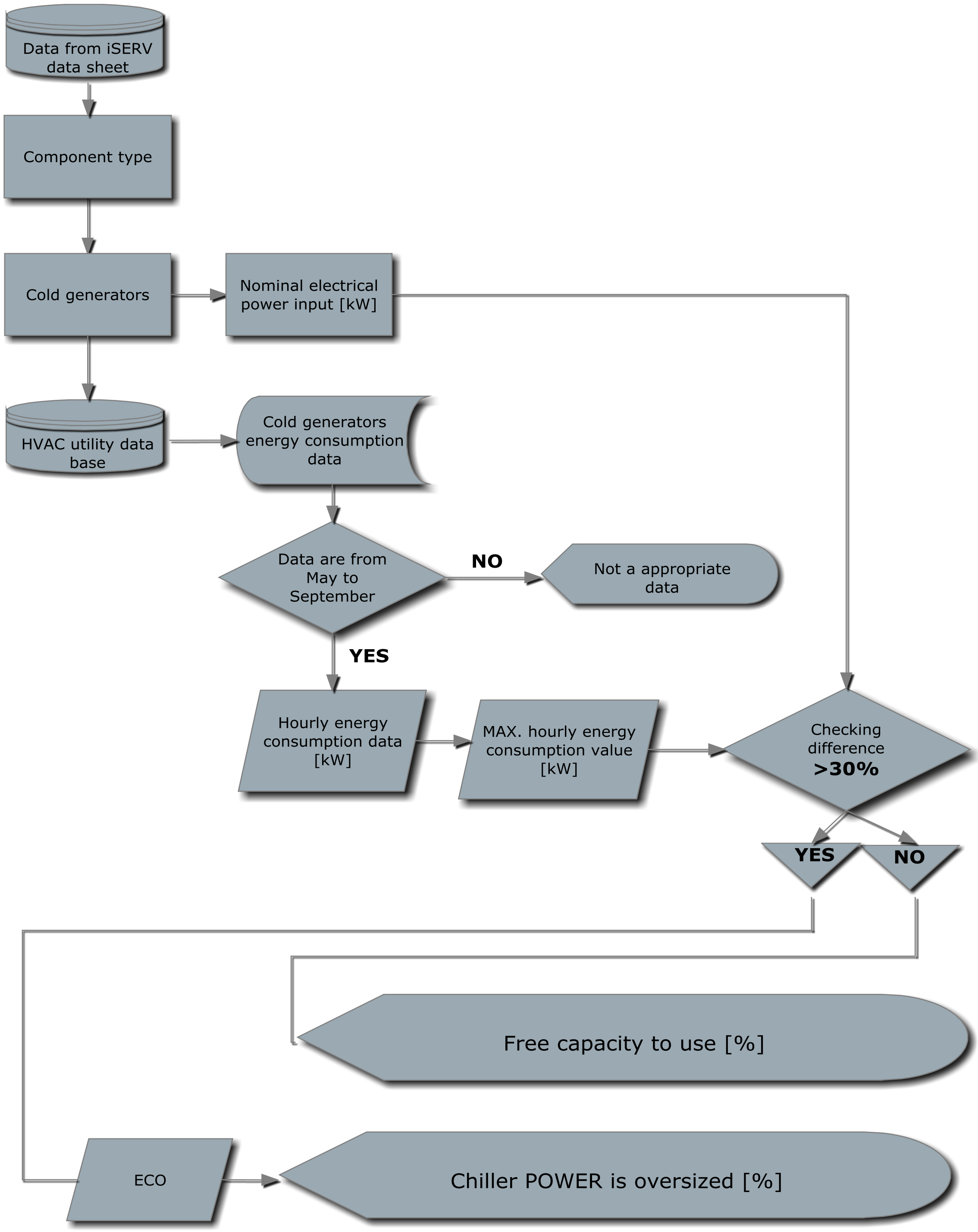
6.1.10.2 *HVAC component data*

- Nominal electric power input
- Nominal cooling capacity

6.1.10.3 *Schedule of Setpoint and Occupancy*

- T - set point of indoor air temperature
- Number of operating hours

6.1.11 Algorithm for ECO detection



7 Priority 5

7.1 P3.12 Replace duct when leaking

7.1.1 Existing subsystems on which the ECO may apply

- Air-water based system
- All water based system

7.1.2 Considered actions

You have to replace ducts if they are leaking.

7.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

Technical documentation of building.

7.1.4 Technical observations to be made on site

You have to check the condition of the ducts.

7.1.5 Monitoring of existing situations

- Water or air flow rate

7.1.6 Criterion for ECO applicability

If ducts are destroyed you have to replace them.

7.1.7 Recommendation for realization of ECO

By replacing ducts the losses are reduced.

You could examine water or air flow rate of each duct (or all duct) as function of operating time (as % of cooling time) and then to compare to nominal water or air flow rate. This comparison should be made during a typical period to avoid drawing bad conclusion.

If results show big difference, we can conclude that the duct is leaking.

7.1.8 Additional support

7.1.9 Remarks

7.1.10 Input data required for ECO identification

7.1.10.1 <u>HVAC sensor data</u>

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling
- flow rate of supply fan
- flow rate of extract fan
- flow rate of refrigerant

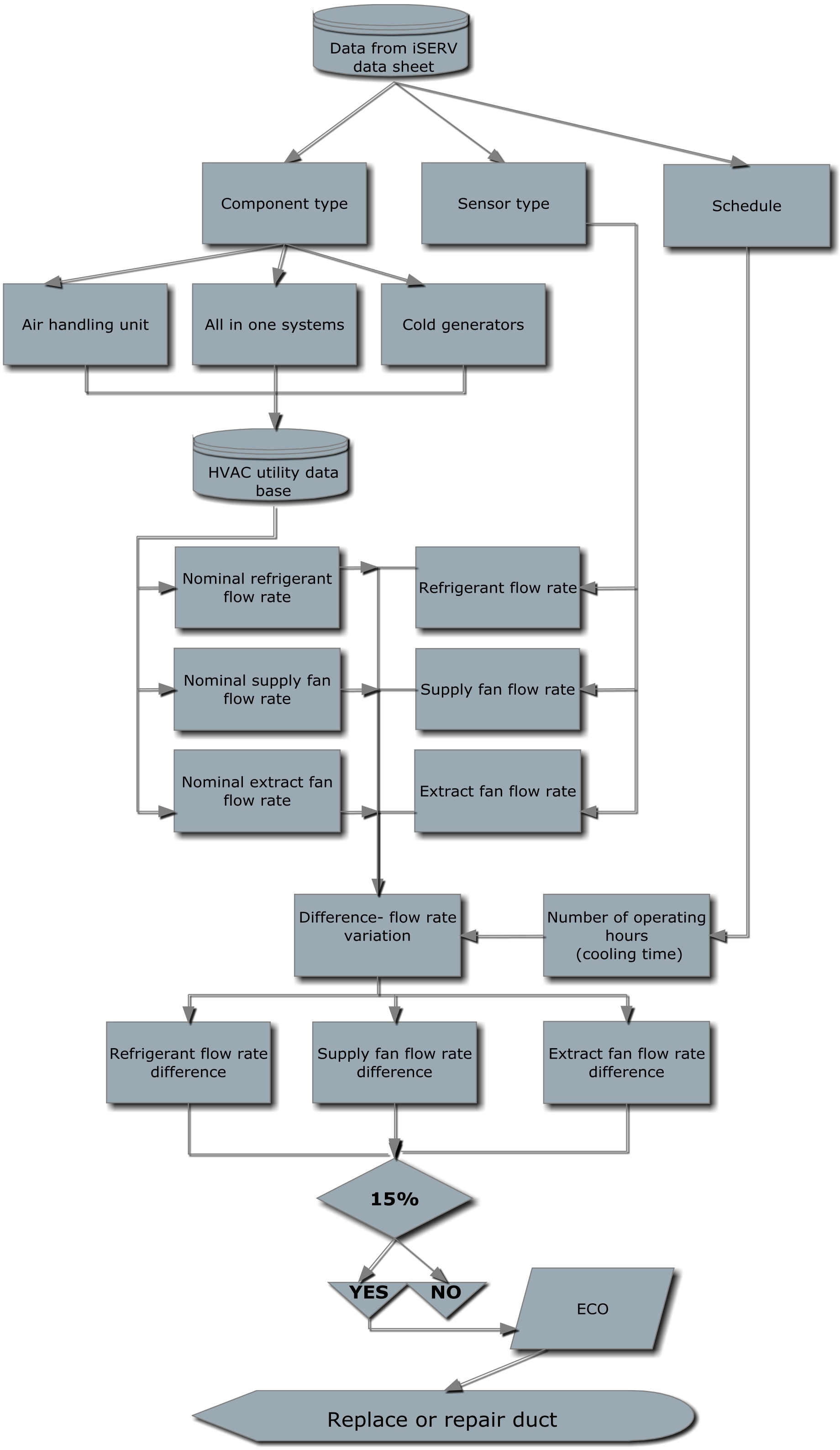
7.1.10.2 <u>HVAC component data</u>

- Nominal flow rate of supply fan
- Nominal flow rate of extract fan
- Nominal refrigerant fluid flow rate
- Pressure specification of HVAC equipment

7.1.10.3 <u>Schedule of Setpoint and Occupancy</u>

- Number of operating hours (cooling time)

7.1.11 Algorithm for ECO detection



7.2 O4.6 Eliminate air leaks (AHU, packaged systems)

7.2.1 Existing subsystems on which the ECO may apply

- Air-water based system

7.2.2 Considered actions

You have to replace ducts if they are leaking.

7.2.3 Technical data to request to owner/manager or to find directly (manufacturer data)

Technical documentation of building.

7.2.4 Technical observations to be made on site

You have to check the condition of the ducts.

7.2.5 Monitoring of existing situations

- Air flow rate

7.2.6 Criterion for ECO applicability

If ducts are destroyed you have to replace them.

7.2.7 Recommendation for realization of ECO

By replacing ducts the losses are reduced.

You could examine air flow rate of each duct (or all duct) as function of operating time (as % of cooling time) and then to compare to nominal air flow rate. This comparison should be made during a typical period to avoid drawing bad conclusion.

If results show big difference, we can conclude that the duct is leaking.

7.2.8 Additional support

7.2.9 Remarks

7.2.10 Input data required for ECO identification

7.2.10.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling
- flow rate of supply fan
- flow rate of extract fan

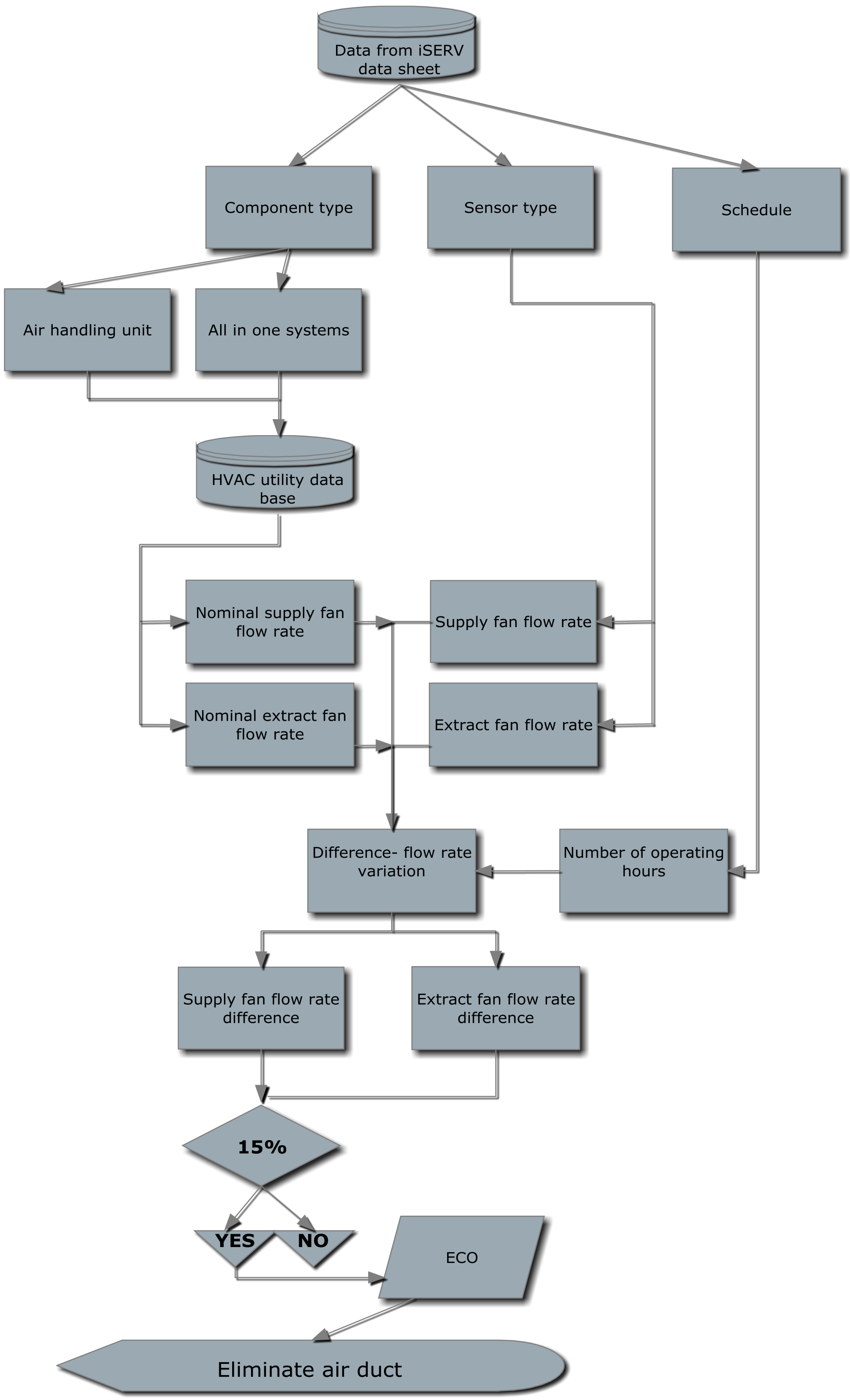
7.2.10.2 HVAC component data

- Nominal flow rate of supply fan
- Nominal flow rate of extract fan
- Pressure specification of HVAC equipment

7.2.10.3 Schedule of Setpoint and Occupancy

- Number of operating hours

7.2.11 Algorithm for ECO detection



8 Priority Other

8.1 P2.4 Repipe chillers or compressor in series or parallel to optimize circuiting

8.1.1 Existing subsystems on which the ECO may apply

Water based system which incorporate multiple chillers and operating control.

8.1.2 Considered action

You could consider to modify ductwork to operate chillers in series/parallel.

8.1.3 Technical data to request to owner/manager or to find directly (manufacturer data)

- Number of functioning hours for each compressor
- Refrigerant type of each chiller
- Nominal consumption of each compressor
- COP, EER, SEER, IPLV of each chiller

8.1.4 Technical observations to be made on site

Description of water loop architecture

8.1.5 Monitoring of existing situations

- Temperature of inlet and outlet cold water
- You could identify variable cooling production (part load ratio)
- Consumption of each chiller
- Consumption of each pump
- Water flow rate

8.1.6 Criterion for ECO applicability

You could examine optimum arrangement balancing pump and chiller savings.

8.1.7 Recommendation for realization of ECO

To verify the possibilities of control using refrigeration control (ECO P2.5) or using a BEM (ECO P1.1)

8.1.8 Additional support

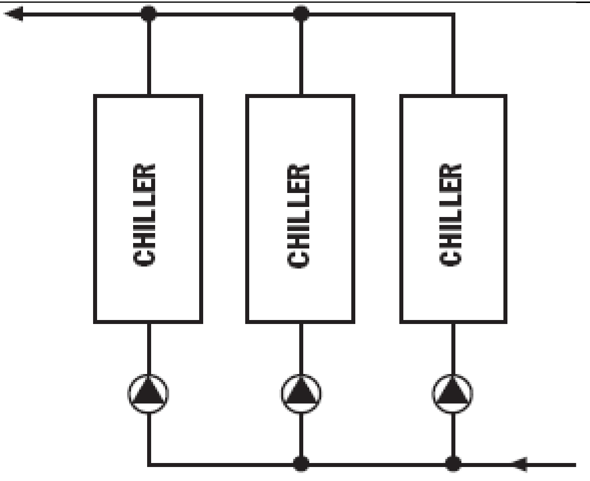
Parallel pumps are used to control individual chiller flow rate at equal chilled-water temperature set points.(classical architecture in Europe?)

In the USA, headered pumps are used to have a constant chilled-water flow rate at different chilled-water temperature.

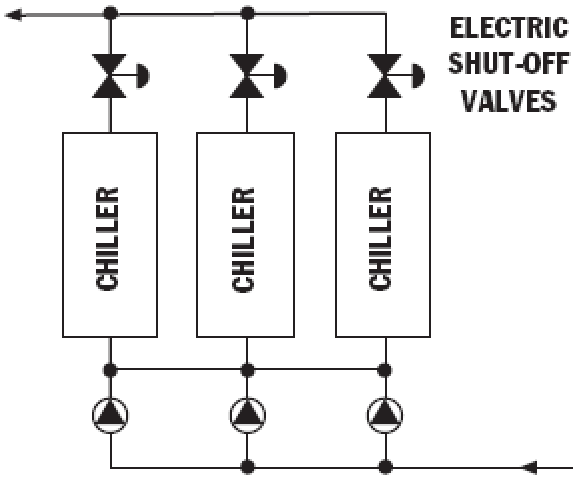
Unequal chillers are designed either

- To handle an off-peak load

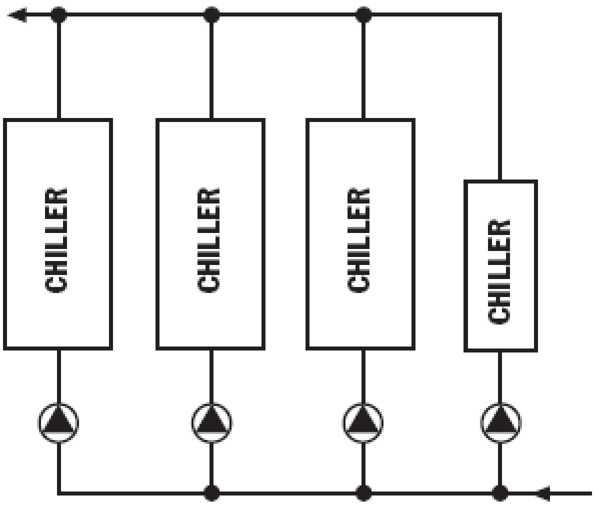
- Or to handle off-peak load and be available for supporting the full load in event of failure of another chiller



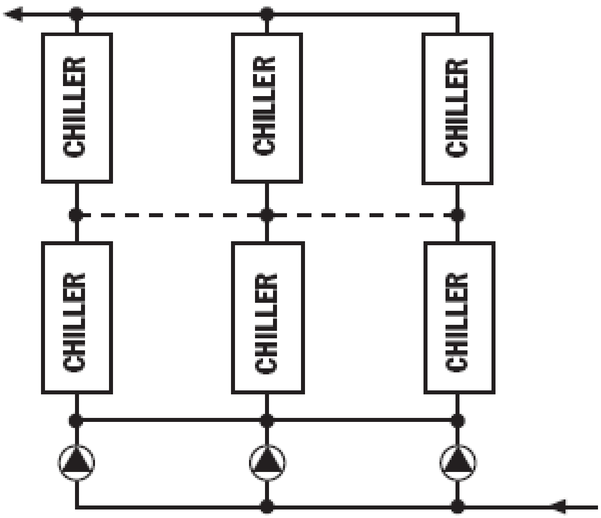
Equal chiller and parallel pumps



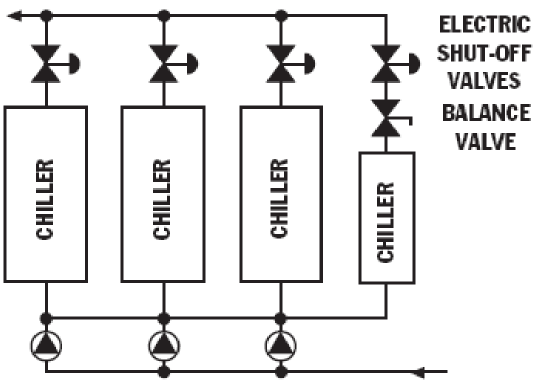
Equal chillers and headered pumps



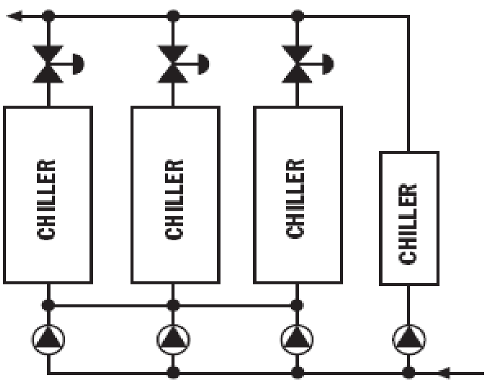
Unequal chillers and parallel pump



Series/Parallel chillers



All pump headered



Equal chillers headered

8.1.9 Input data required for ECO identification

8.1.9.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature

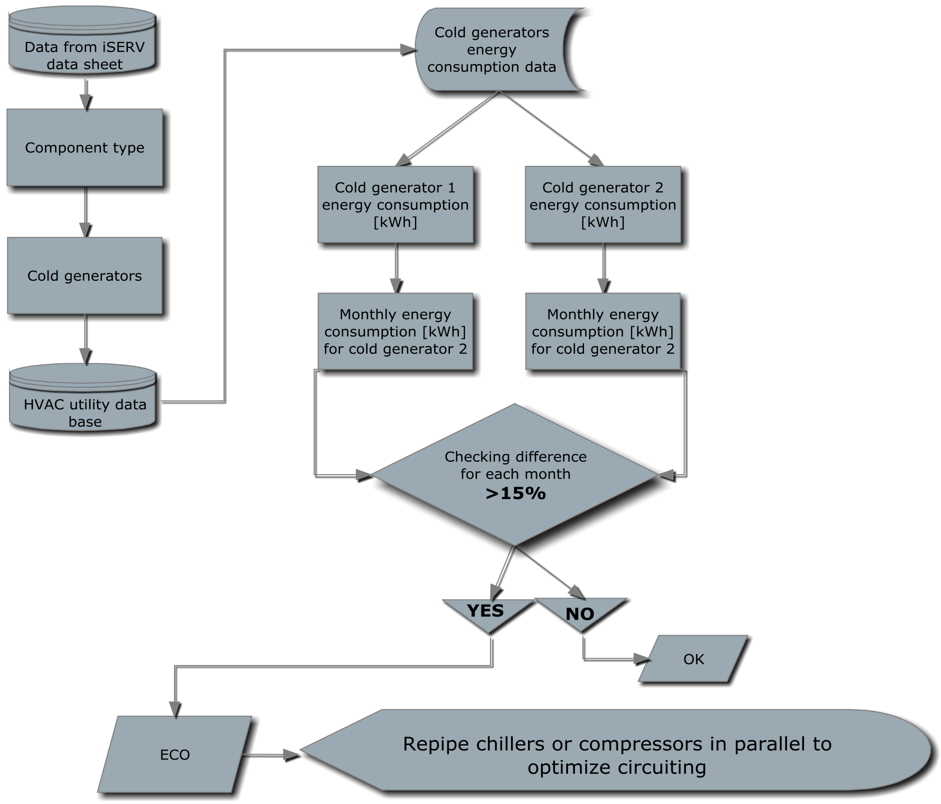
8.1.9.2 HVAC component data

- Nominal electric power input
- Nominal cooling capacity

8.1.9.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Number of operating hours

8.1.10 Algorithm for ECO detection



8.2 *P2.13 Consider cool storage applications (chilled water, water ice, other phase changing material)*

8.2.1 Existing subsystems on which the ECO may apply

The subsystem is air conditioning HVAC system.

The subsystem is chiller.

8.2.2 Considered actions

You could smooth peak consumption using this option

You could consider cool storage applications to store chilled water. It can be generated by using indirect free cooling without chiller running.

8.2.3 Technical data to request to owner/manager or to find directly (manufacturer data)

8.2.4 Technical observations to be made on site

Building already has a storage system

8.2.5 Monitoring of existing situations

8.2.6 Criterion for ECO applicability

Cold storage system installation is feasible for net areas larger than 10000m2.

8.2.7 Recommendation for realization of ECO

Supply cold water in building located in continental climates to provide a better efficiency of the system.

8.2.8 Additional support

8.2.9 Remarks

8.2.10 Input data required for ECO identification

8.2.10.1 HVAC sensor data

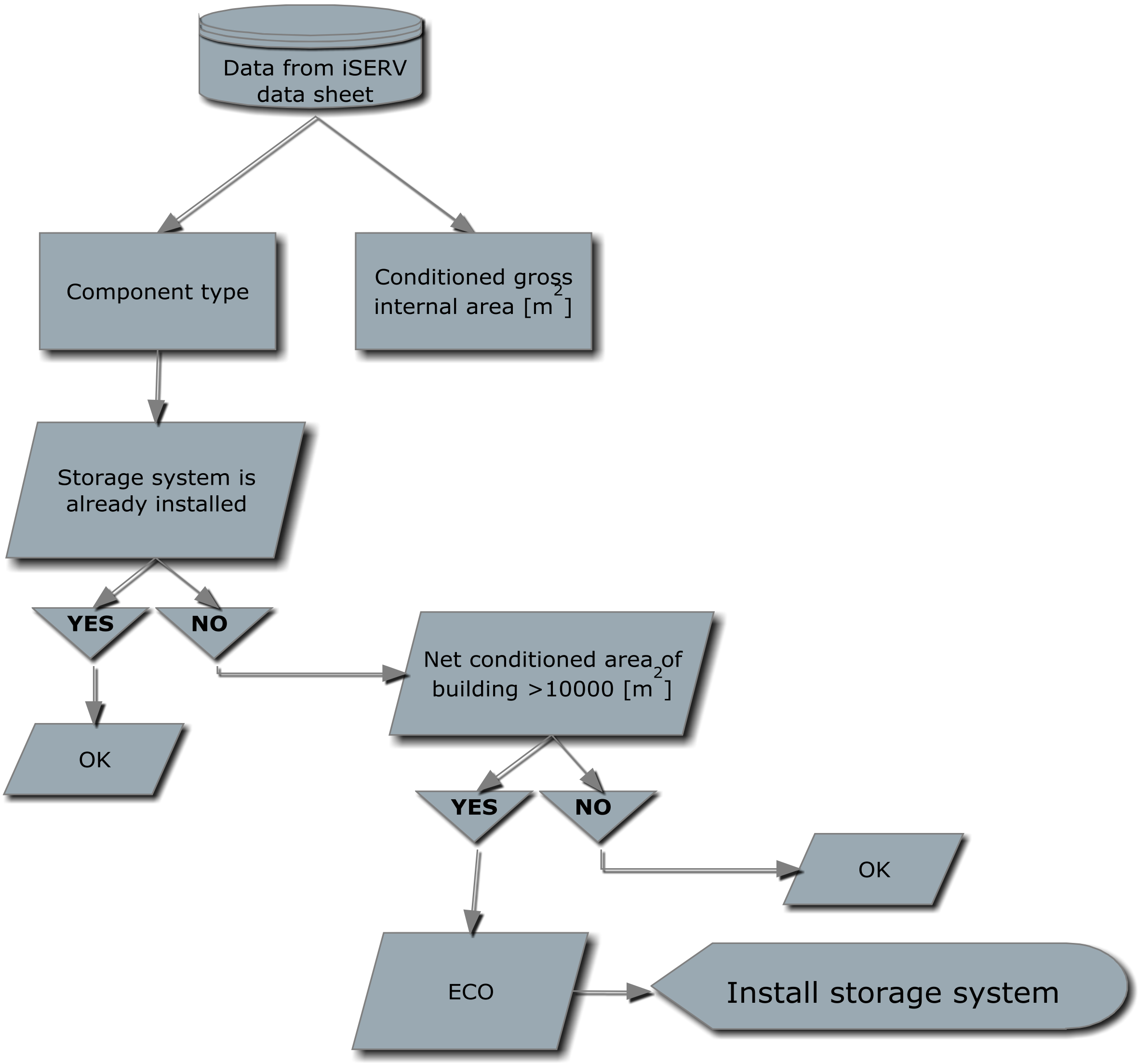
8.2.10.2 HVAC component data

- Net cooling area of building
- Building already has a storage system

8.2.10.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature

8.2.11 Algorithm for ECO detection



To reduce and to optimize energy consumption of chillers the algorithm checks if it is possible and reasonable to install cold storage system into HVAC system:

- The algorithm first checks if the HVAC system has a cold storage installed. If this is not the case, the algorithm will check how big the net cooling area of the building is. The threshold value is 10000m^2, i.e. cold storage system installation is feasible for net areas larger than 10000m^2.

8.3 P3.1 Reduce motor power (according to fan power demand) when oversized

8.3.1 The following ECOs could be considered depending on type of auxiliaries:

- Pumps
- Fans

8.3.2 For fans you could consider here under options:

- Reduce motor size ECO P3.1
- Use the best Eurovent class of fan ECO P3.3
- Apply variable flow rate fan control ECO P3.6
- Consider applying demand-controlled ventilation ECO P3.10
- Replace duct when leaking ECO P3.12

8.3.3 For pumps you could consider hereunder options:

- Use the best class of pumps ECO P4.1
- Install variable volume pumping ECO P4.5

8.3.4 Maintenance operation

- Shut off auxiliaries when not required ECO O2.2

8.3.5 Reference:

Energy Consumption Characteristics of Commercial Building HVAC Systems Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation by Westphalen

8.3.6 Input data required for ECO identification

8.3.6.1 *HVAC sensor data*

- T - outdoor air temperature
- T - indoor air temperature
- Condition of valve for heating
- ondition of valve for cooling
- Flow rate
- Temperature of inlet and outlet cold water
- Refrigerant fluid flow rate
- inlet pressure
- outlet pressure
- Pressure of refrigerant fluid
- Temperature of refrigerant fluid
- Temperature of refrigerant fluid at the outlet
- Temperature of cooling fluid at the inlet
- Temperature of cooling fluid at the outlet
- Temperature heat carrier fluid at the inlet
- Temperature heat carrier fluid at the outlet

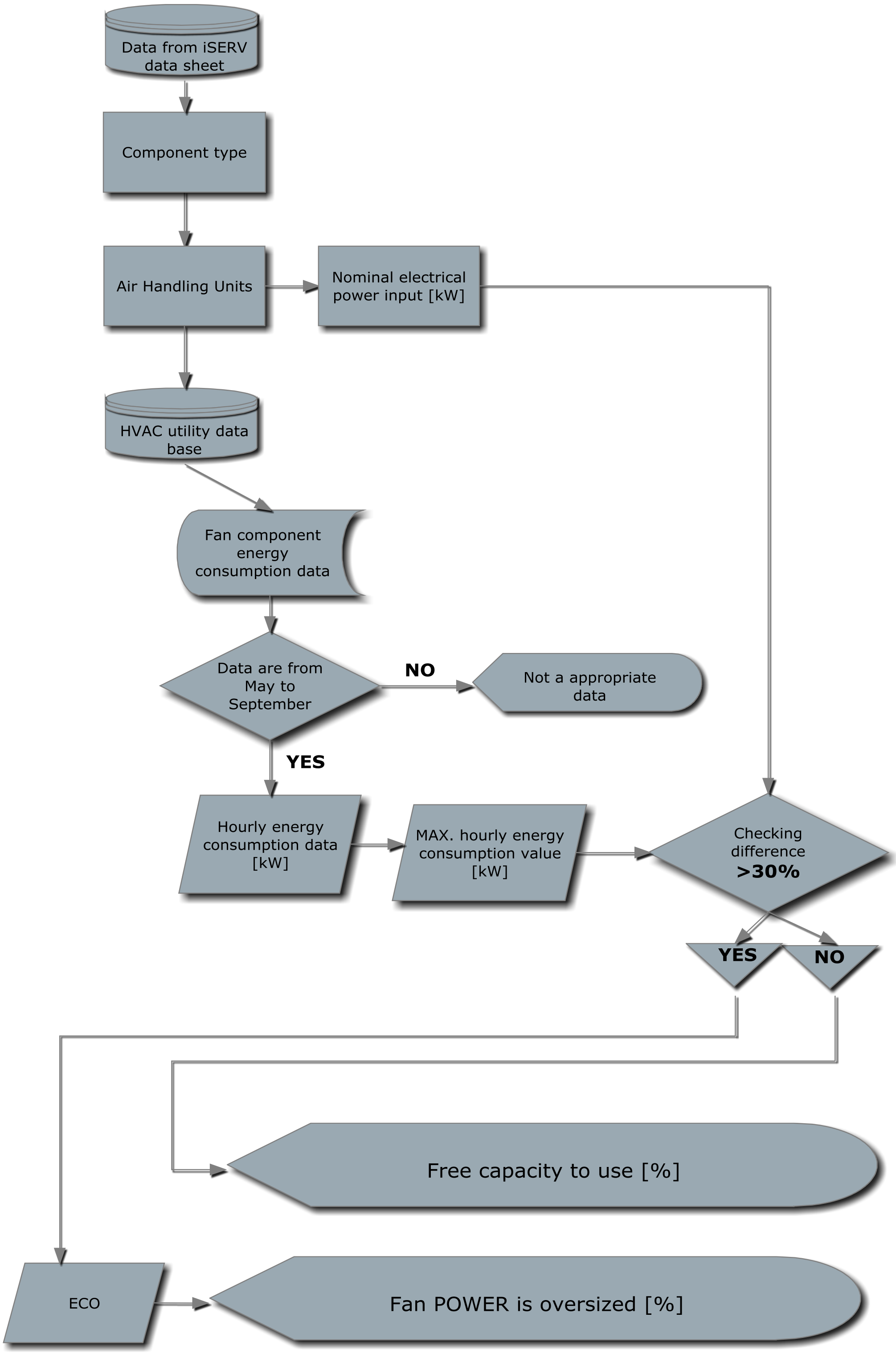
8.3.6.2 *HVAC component data*

- Nominal speed (rpm)
- Nominal flow rate
- Nominal electric power input

8.3.6.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Temperature regime
- Schedule of occupancy

8.3.7 Algorithm for ECO detection



8.4 O2.7 Sequence heating and cooling

8.4.1 Existing subsystems on which the ECO may apply

- Water-Based system
- Air and water based system

Subsystem 1: Central control

Central control of heating and cooling generators and associated water circuit (winter summer mode)

Subsystem 2: Local control

Local control of heating and cooling distribution (zone temperature control)

8.4.2 Considered action

Action 1 to be applied to subsystem 1 central control

- To check HVAC system central control
- To define better cooling season and heating season
- To stop heating and cooling generators and associated auxiliary (e.g. pumps) equipment according to previously defined seasons

Action 2 to be applied to subsystem 2 local control

The target is a dead-band, thus this ECO is examined as a problem of controller. But, possible problems of interaction between heating and cooling could also be: a temperature sensor that isn't calibrated or a vane fault.

8.4.3 Technical data to request to owner/manager or to find directly (manufacturer data)

- To determine system type: 2 pipes or 4 pipes

Specific data for subsystem 1 Central control

- To determine the type of control for heating/cooling, i.e. Winter/Summer mode is manual or auto. When manual, how are determined the seasons?
- Number of times operation comes to change mode.

Specific data for subsystem 2 Local control

- To determine how are controlled terminal units and coils
- Technical observations to be made on site
- All inputs of SimAudit are required to simulate audited building and to evaluate energy savings or to operate HVAC system.

You can identify 2 pipes system by recognition of the following architecture type (see figure 1).

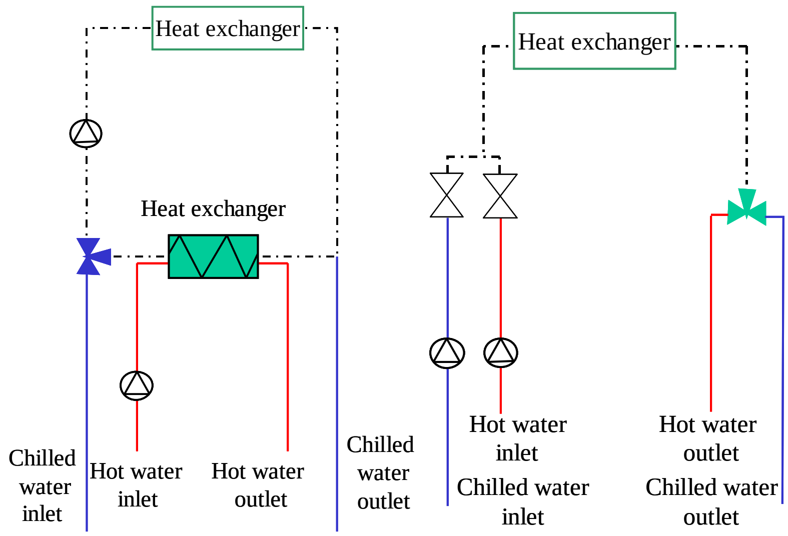


Figure 1 Change-over 2 pipes system without/with mixing

There are 2 distinct coils for heating and cooling for 4 pipes system (see figure 2)

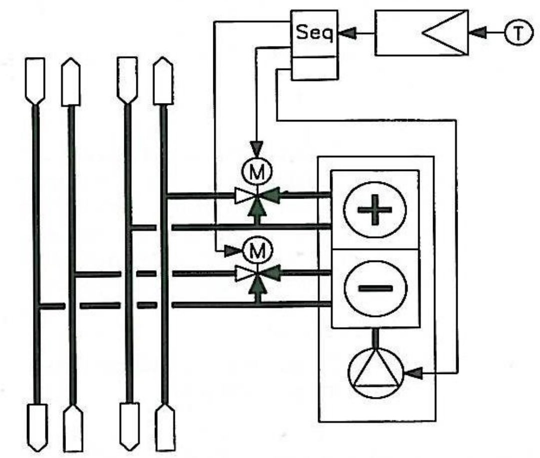


Figure 2 4 pipes system

8.4.4 Monitoring of existing situations

Specific monitoring for subsystem 1 Central control

Inputs related to SimAudit calibration have to be monitored

Specific monitoring for subsystem 2 Local control

You could test sequence by forcing controls through controller interface and check position/operation of control valve, damper….

8.4.5 Criterion for ECO applicability

Criterion for subsystem 1 central control

- 4 Pipes

You can simulate your building with SimAudit to examine cooling demand and heating demand to define cooling mode and heating mode.

Indeed, you can plot cooling demand and heating demand as a function of time (see figure 3). Heating generator can be stopped when there isn't heating demand and on the contrary can be switched when necessary. Similarly, cooling season can be determined.

If pumps of water circuit are switched on all the year round, it is possible to switch off auxiliary when they are not required. **Electrical consumption of pumps is reduced by 33% i.e. a reduction of 0.9kWh/m²** for a typical office building (total consumption of 120kWh/m²) in Belgium with 2 separated pumps.

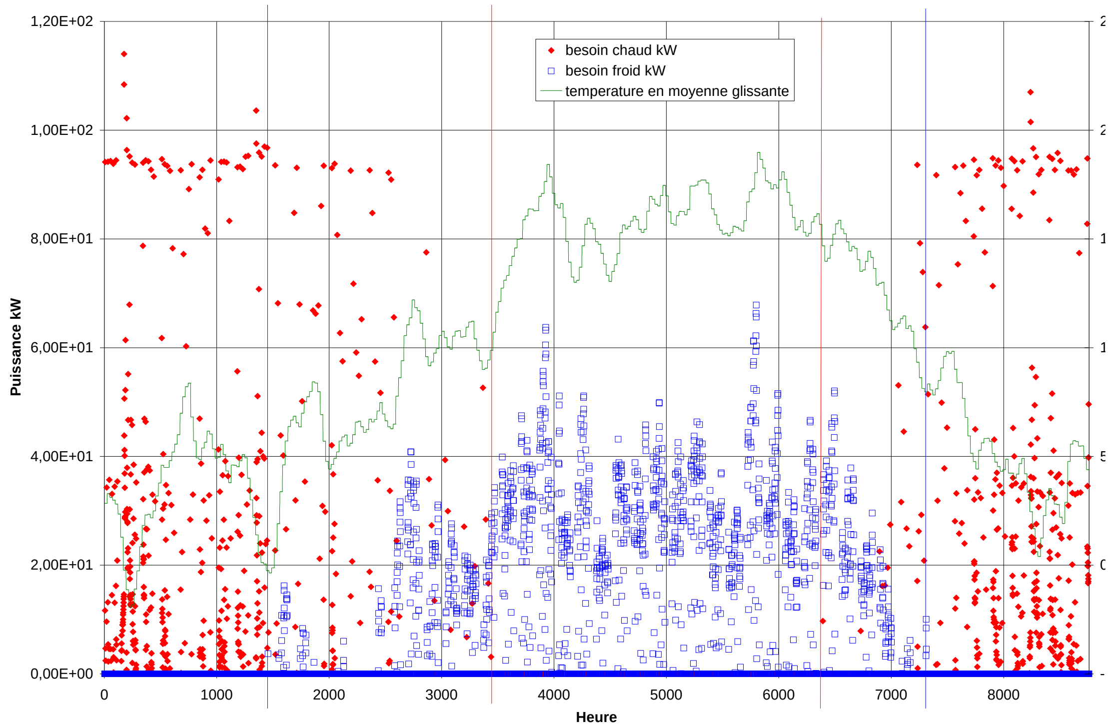


Figure 3 Results of cooling demand and heating demand for a simulated building

Red plots correspond to heating demand and blue plots to cooling demand.

Red lines limits heating season and blue lines limits cooling season.

- 2 Pipes

For a 2 pipes system, a definition of cooling and heating season is needed to system operation. Changeover vane must be activated according to these seasons.

A simulation could be made to evaluate energy and thermal comfort impact of a fixed date. Auxiliary equipment could also be switched off when not required. Thermal comfort impact can be examined according to [1].

Criterion for subsystem 2 local control

- 4 Pipes system

On figure 4, the temperature set points (T1 and T2) can be modified to sequence heating (1) and cooling (2).

The dead-band (see 1 on figure 4) could disappear when temperature measurement is not calibrated or not accurate. Figure 5 shows a problem of cool and heat supply timing.

You should estimate occurrences of simultaneous heating and cooling demand. You could consider temperature set points (and possible problems of measurement) and hourly outside temperature to identify interactions of cooling/heating.

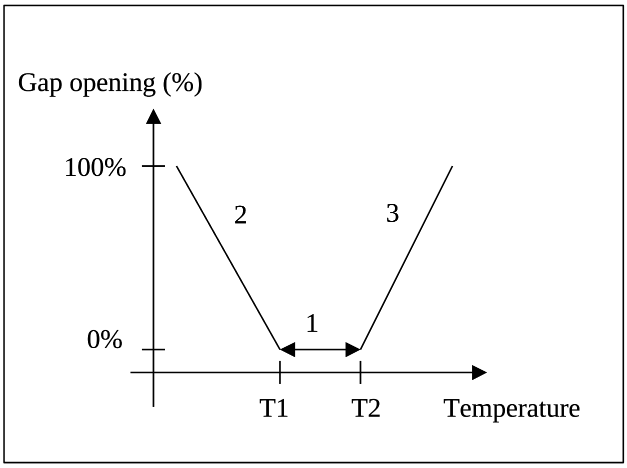


Figure 4 Correct dead-band

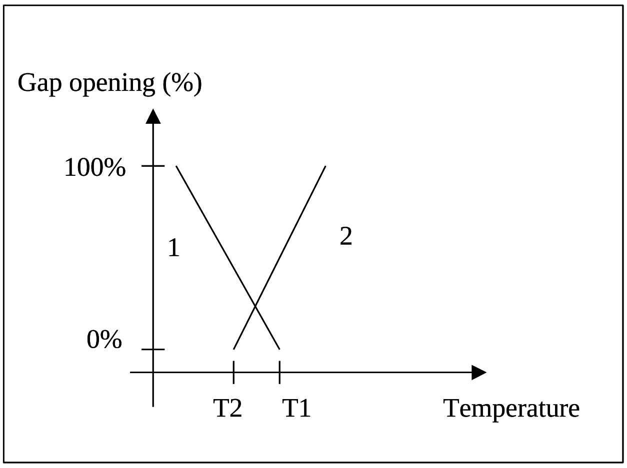


Figure 5 Problem of dead-band

- 2 pipes system

The same methodology must be applied.

Local controller splits the control law for cooling and heating, and there are two set points as for a 4 pipes system. The controller is often manual (centralized by zone) and perhaps automatically switched by a temperature sensor located at water terminal unit inlet, this sensor needs calibrating (figure 6).

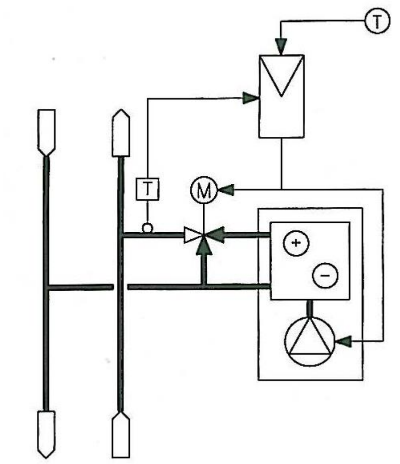


Figure 6 Automatic selection of control law by water temperature inlet

8.4.6 Recommendation for realization of ECO

Recommendation for subsystem 1 Central control

- For 4 pipes systems, you could meet operator one week before the date estimated by simulation tool.
- For 2 pipes system an automatic changeover control is proposed in ECO form P1.3 (Modify controls in order to sequence heating and cooling). Consumption of cooling demand (thermal) is reduced by 6.2%, it corresponds to a reduction of 0.15 kWh/m²(thermal) (total cooling demand 32.2kWh/m² (thermal)). A BEMs is required (if not a big number of operations is required to switch-over the control mode in the building to achieve thermal comfort of occupant)

Recommendation for subsystem 2 Local control

You can maintain proper temperature set point ECO O2.4

8.4.7 Input data required for ECO identification

8.4.7.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- condition of valve for heating
- condition of valve for cooling
- Temperature of inlet and outlet cold water
- T - set point of indoor air temperature

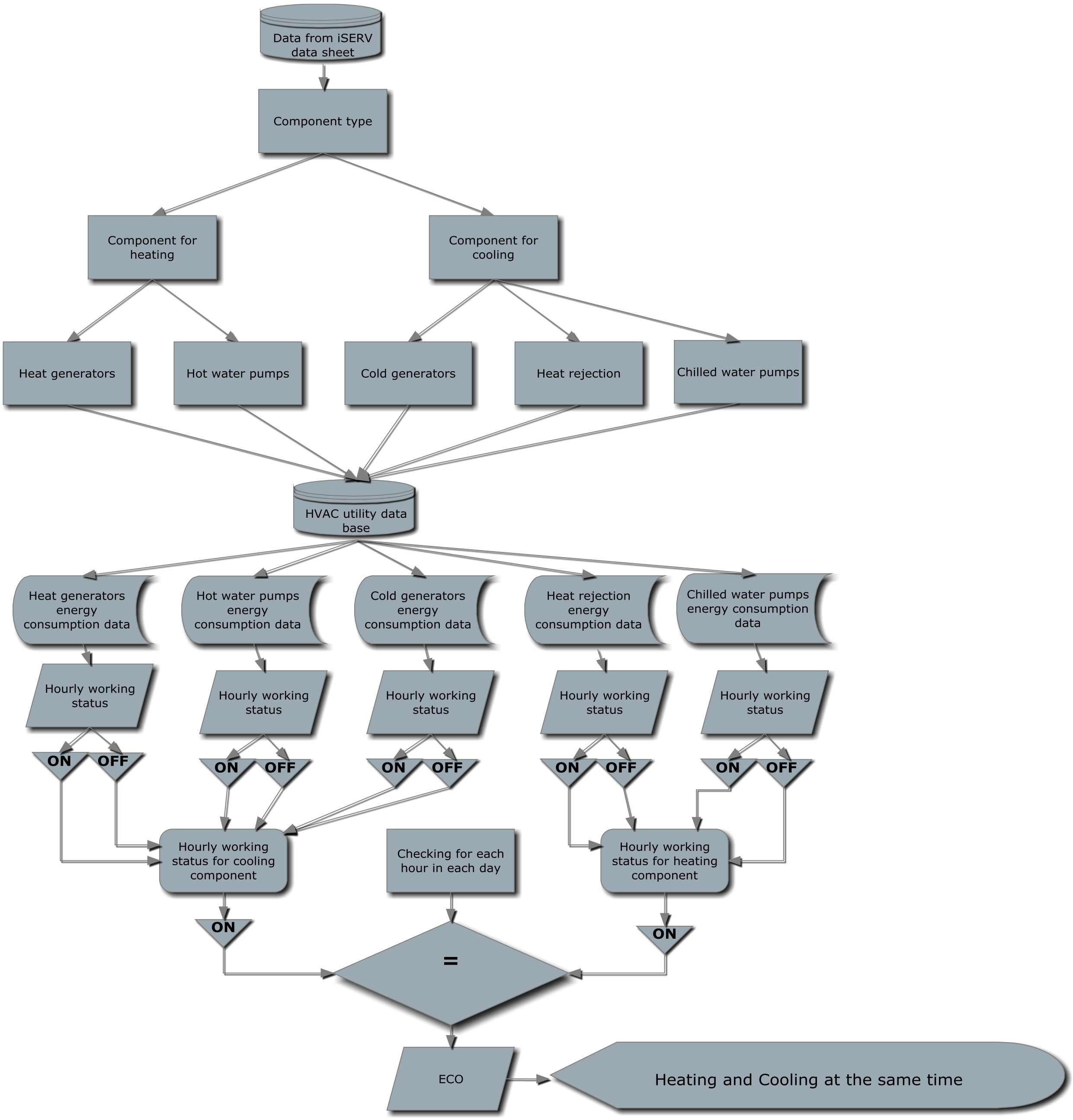
8.4.7.2 HVAC component data

- Nominal electric power input
- Nominal cooling capacity

8.4.7.3 Schedule of Setpoint and Occupancy

- Number of operating hours
- Occupancy schedule per zone

8.4.8 Algorithm for ECO detection



8.5 O3.3 Operate chiller in series or parallel

8.5.1 Existing subsystems on which the ECO may apply

- Air-water based system
- All water based system

These subsystems distribute poorly the load.

You could consider also if:

- Chillers are in parallel with identical design, COP and part load characteristics: subsystem 1
- Different chillers are in parallel: subsystem 2
- Chillers are in series with identical design, COP and part load characteristics: subsystem 3
- Different chillers are in series: subsystem 4

8.5.2 Considered action

To sequence chiller to have a better overall efficiency

8.5.3 Technical data to request to owner/manager or to find directly (manufacturer data)

- Number of functioning hours for each compressor
- Refrigerant type of each chiller
- Nominal consumption of each compressor
- COP, EER, SEER, IPLV of each chiller

8.5.4 Technical observations to be made on site

Description of water loop architecture

8.5.5 Monitoring of existing situations

Power consumption of each chiller as a function of the leaving condenser water temperature and the chilled-water supply temperature.

8.5.6 Criterion for ECO applicability

8.5.6.1 *Criteria for chillers in parallel with identical design, COPs and part load characteristics (subsystem 1)*

$$Q_{opti} = \frac{Q_{load}}{\sum_{i=1}^{N} Q_{desi}} Q_{desi}$$

Where Q_{opti} is optimal loading of chiller i; Q_{load} is total chiller load; Q_{desi} is the cooling capacity of i th chiller at design conditions and N is the number of chillers operating.

The loading determine with previous equation gives a minimum of power consumption when the chillers are operating at loads greater than the point at which the maximum COP occurs.

8.5.6.2 *Criteria for different chillers in parallel (subsystem 2) (will be studied)*

You consider two type of control:

- To use individual chilled-water flow rate control (using a two-way valve) at equal chilled-water set points.

- To use different chilled-water set point

8.5.7 Recommendation for realization of ECO

Realization for chillers in parallel with identical design, COP and part load characteristics (subsystem 1)

You could control individual chilled-water flow rate to achieve these load distribution

8.5.8 Additional support

8.5.9 References

ASHRAE Handbook-HVAC applications, 2007, 41.21 to 41.25

8.5.10 Input data required for ECO identification

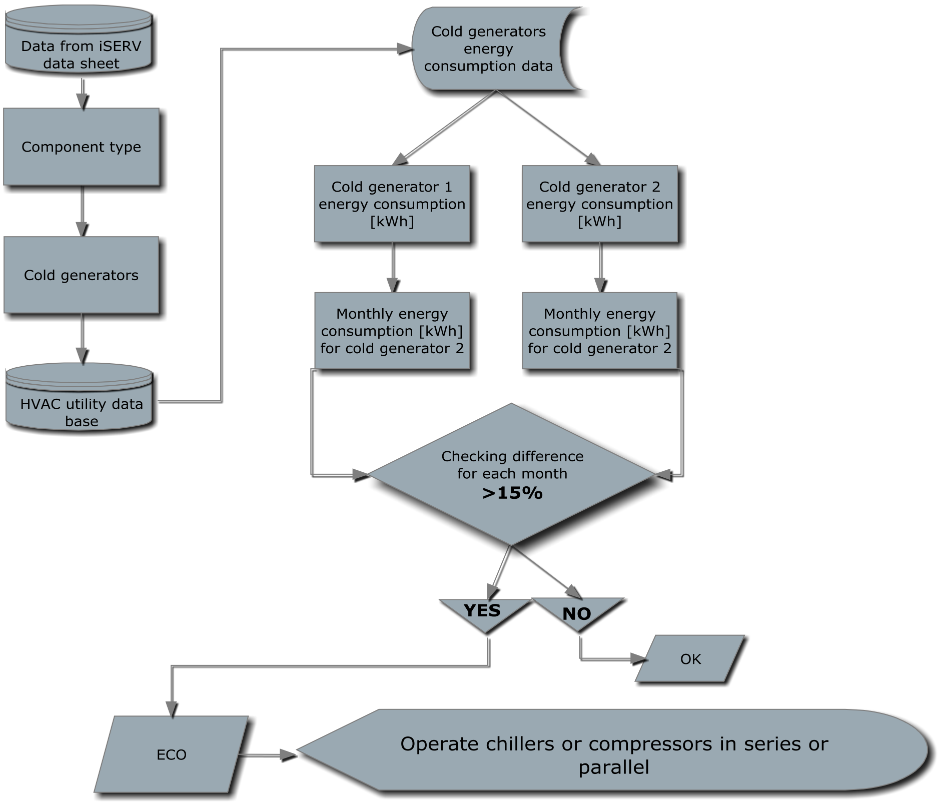
8.5.10.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- Condition of valve for heating
- Condition of valve for cooling
- Flow rate
- Temperature of inlet and outlet cold water
- Refrigerant fluid flow rate

8.5.10.2 HVAC component data

- Nominal electric power input

8.5.11 Algorithm for ECO detection



8.6 O3.14 Check (reversible) chiller stand-by losses

8.6.1 Existing subsystems on which the ECO may apply

Water based system with incorporate multiple chillers and associated control.

8.6.2 Considered actions

To reduce exist energy consumption and to improve the efficient design and operation of the chilled water plant and air-conditioning system.

8.6.3 Technical data to request to owner/manager or to find directly (manufacturer data)

You can search for rated power on nameplate, rated current, rated voltage, rated frequency and speed

- Number of functioning hours
- Refrigerant type of chiller
- Nominal consumption of chiller plant
- COP, EER, SEER, IPLV of chiller
- Data of water chiller
- Nominal electric power of chiller plant
- Stand-by time of chiller

8.6.4 Technical observations to be made on site

8.6.5 Monitoring of existing situations

- Total operating time of the chiller plant
- Measured energy consumption of chiller plant
- Stand-by time of chiller

8.6.6 Criterion for ECO applicability

We have to check if the existing stand-by losses of chiller are in the range of best efficient types.

- You could examine optimum arrangement balancing chiller stand-by mode and chiller savings.

8.6.7 Recommendation for realization of ECO

There are basically two options to reduce the standby power consumption: behavioral and technical.

The first one involves better consumer awareness and education on standby energy consumption.

The second option for reducing standby power consumption in most appliances is the adoption of technological innovations. It is estimated that redesigning appliance circuits can reduce standby power consumption up to 90%. In fact, manufacturers have introduced many power-saving features in the past decade, particularly for those products that are plugged in all the time. These features are typically the standby or sleep modes; when an appliance is required to perform fewer functions or it is waiting for a signal to be fully operational, it is generally designed to go into standby mode in which the product consumes much less power. Some parts of the appliance remain on standby till the power switch is activated or input received from a remote control device.

One of the areas where substantial energy is consumed when the appliance is on standby or switched off is the power supply system. With the recent innovations, it is possible to reduce the no-load losses while providing very high conversion efficiencies. New generation power transformers adopting electronic components are capable of reducing the standby power consumption.

8.6.8 Additional support

8.6.9 References

W. Mungwittitkul and B. Mohanty, Energy efficiency of office equipment in commercial buildings: The case of Thailand, Energy, Vol. 22, No. 7, pp. 673-680, 1997.

Alan Meier, Standby power – A quiet use of energy, CADDET Energy Efficiency Newsletter, No. 4, 1999.

Takaji Matsunaga, Survey on actual stand-by power consumption of households, 3rd International Workshop on Standby Power, Tokyo, 7-8 February 2001.

Ursula Rath et al, Climate protection through reduction of standby losses in electric appliances and equipment, 2nd International Workshop on Standby Power, Brussels, 18 January 2000.

Tony Marker, Residential standby power consumption in Australia: Results of recent survey work, 3rd International Workshop on Standby Power, Tokyo, 7-8 February 2001.

Swiss Federal Office of Energy, The energy efficiency of computer networks, Switzerland, February 1998.

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Julia Vowles, Standby consumption levels and user awareness in the UK domestic sector, 3rd International Workshop on Standby Power, Tokyo, 7-8 February 2001.

Llyod Harrington and Paula Kleverlaan, Quantification of residential standby power consumption in Australia: Results of recent survey works, Project for the Australian Greenhouse Office, Australia, March 2001.

Lin Jiang et al, Measurement of standby power in Chinese homes, 3rd International Workshop on Standby Power, Tokyo, 7-8 February 2001.

Oliver Sidler, Campagne de mesures sur le fonctionnement en veille des appareils domestiques, Report No. 99.07.092, ADEME, France, 2000.

8.6.10 Input data required for ECO identification

8.6.10.1 HVAC sensor data

- Flow rate
- Temperature of inlet and outlet cold water
- T - set point of indoor air temperature

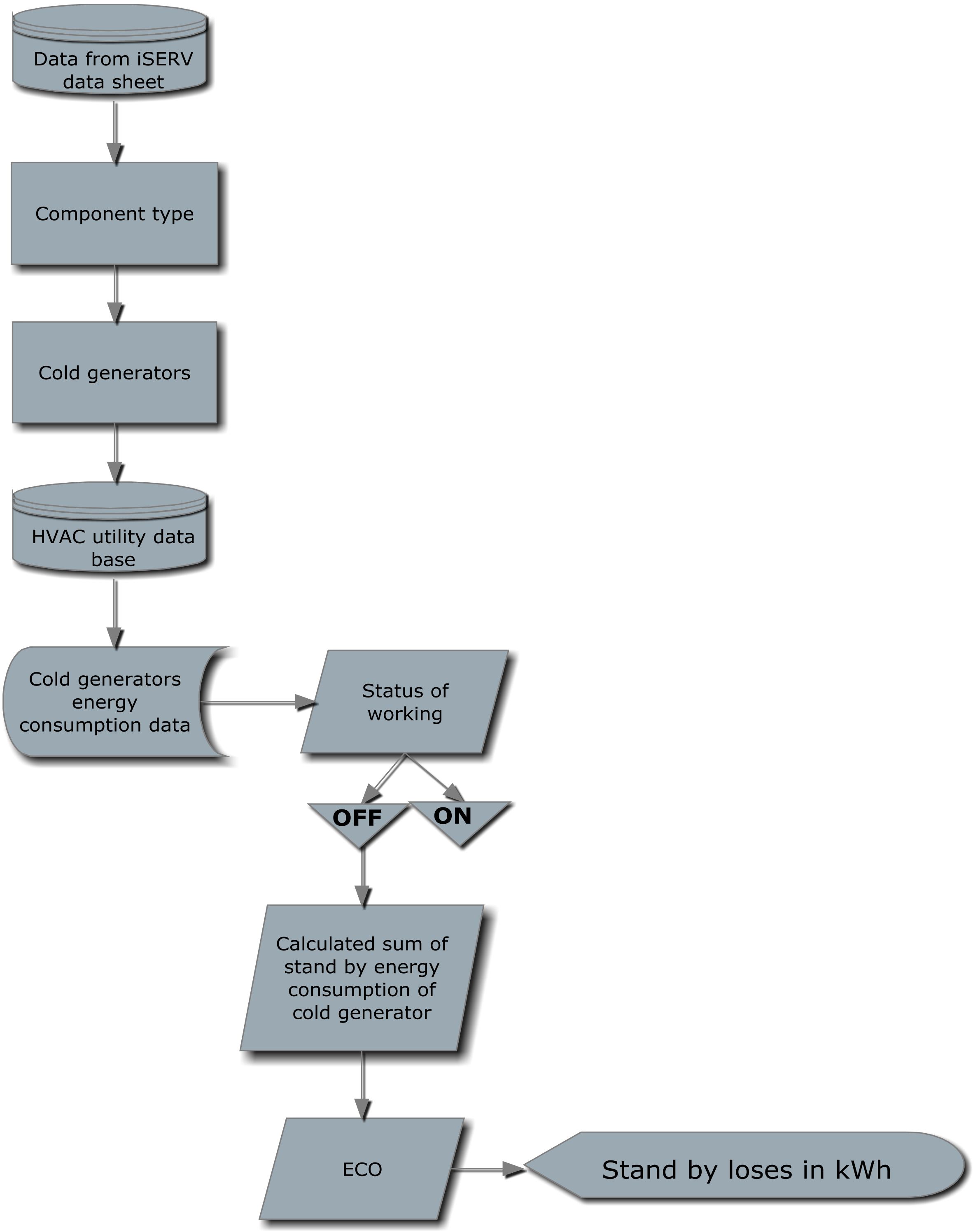
8.6.10.2 HVAC component data

- Rated frequency
- Nominal flow rate
- Nominal electric power input

8.6.10.3 Schedule of Setpoint and Occupancy

- Number of operating hours
- Occupancy schedule per zone

8.6.11 Algorithm for ECO detection



8.7 O4.14 Clean or replace filters regularly

8.7.1 Existing subsystems on which the ECO may apply

- Air based system

8.7.2 Considered actions

To find damaged filters with reason to improve indoor air quality.

8.7.3 Technical data to request to owner/manager or to find directly (manufacturer data)

8.7.4 Technical observations to be on site

Data about the last maintenance of AHU or when the last change of filter was done.

8.7.5 Monitoring of existing situations

- Measured energy consumption of AHU
- Inlet pressure
- Outlet pressure

8.7.6 Criterion for ECO applicability

In case that the pressure drop in relation to the nominal value is high, we can conclude that the filter is dirty or damaged.

8.7.7 Recommendation for realization of ECO

In case that the pressure drop in relation to the nominal value is high you have to clean or replace the filter.

8.7.8 Additional support

8.7.9 Remarks

8.7.10 Input data required for ECO identification

8.7.10.1 HVAC sensor data

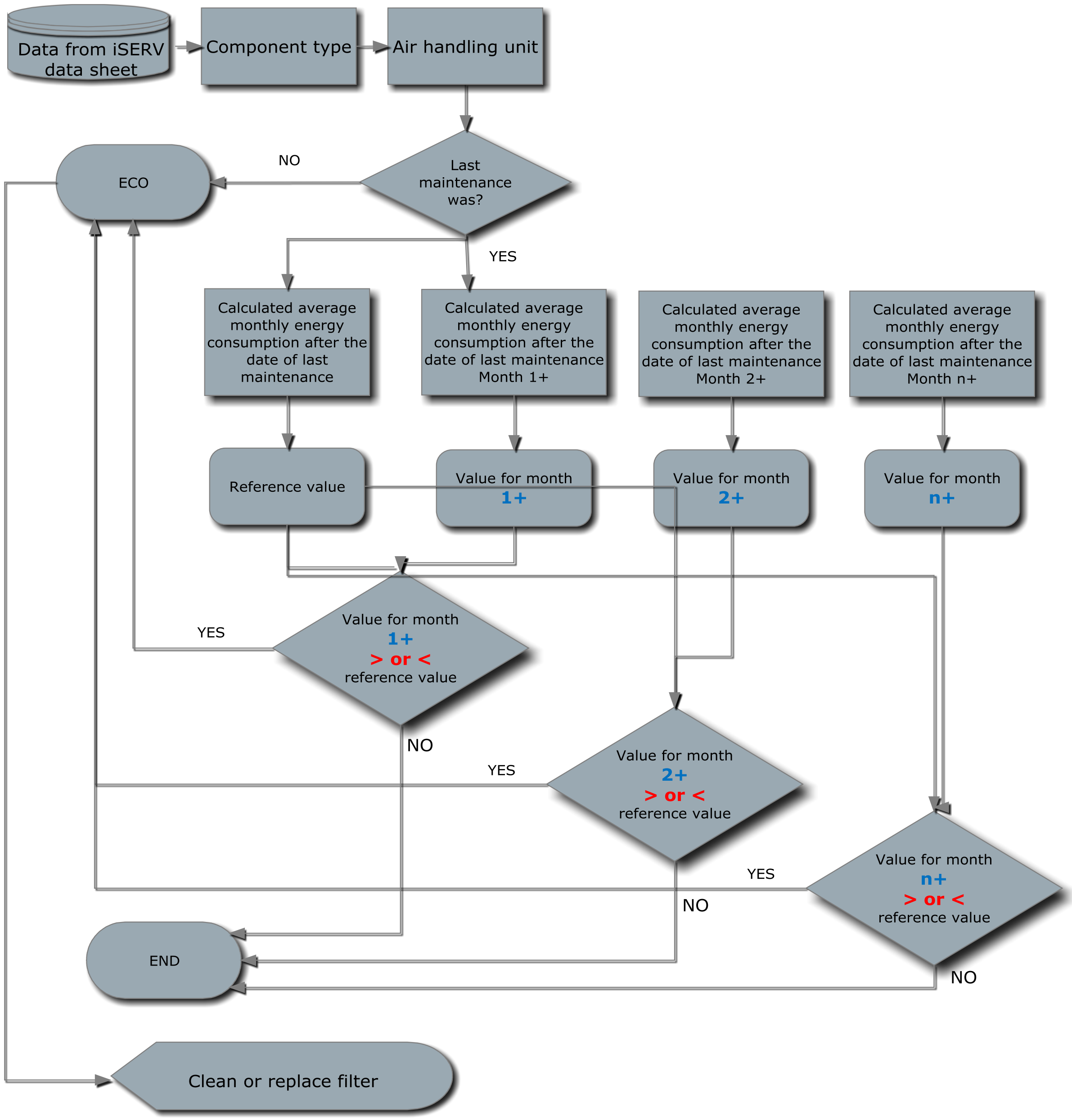
- Pressure drop

8.7.10.2 HVAC component data

- Last maintenance of AHU
- Nominal pressure drop

8.7.10.3 Schedule of Setpoint and Occupancy

8.7.11 Algorithm for ECO detection



To achieve better indoor air quality the algorithm checks if there is any reason to clean or replace filters.

The algorithm calculates the monthly energy consumption after the date of the last maintenance to get a reference value of the AHU energy consumption and then compares it with the average monthly energy consumption for month 1+ to month n+.

The target of this algorithm is not only to find this ECO (clean or replace filters) but also to checks if the position of the supply air duct of the HVAC system is suitable. This has to be studied.

The Algorithm will also be useful for detecting which type of HVAC system (CAV or VAV) is being used. This has to be studied.

8.8 O4.19 Switch off circulation pumps when not required

8.8.1 The following ECOs could be considered depending on type of auxiliaries:

- Pumps

8.8.2 For fans you could consider here under options:

- Reduce motor size ECO P3.1
- Use the best Eurovent class of fan ECO P3.3
- Apply variable flow rate fan control ECO P3.6
- Consider applying demand-controlled ventilation ECO P3.10
- Replace duct when leaking ECO P3.12

8.8.3 For pumps you could consider hereunder options:

- Use the best class of pumps ECO P4.1
- Install variable volume pumping ECO P4.5

8.8.4 Maintenance operation

- Shut off auxiliaries when not required ECO O2.2

8.8.5 Reference:

Energy Consumption Characteristics of Commercial Building HVAC Systems Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation by Westphalen

8.8.6 Input data required for ECO identification

8.8.6.1 HVAC sensor data

- T - outdoor air temperature
- T - indoor air temperature
- Condition of valve for heating
- Condition of valve for cooling
- Flow rate
- Temperature of inlet and outlet cold water
- Refrigerant fluid flow rate
- inlet pressure
- outlet pressure
- Pressure of refrigerant fluid
- Temperature of refrigerant fluid
- Temperature of refrigerant fluid at the outlet
- Temperature of cooling fluid at the inlet
- Temperature of cooling fluid at the outlet
- Temperature heat carrier fluid at the inlet
- Temperature heat carrier fluid at the outlet

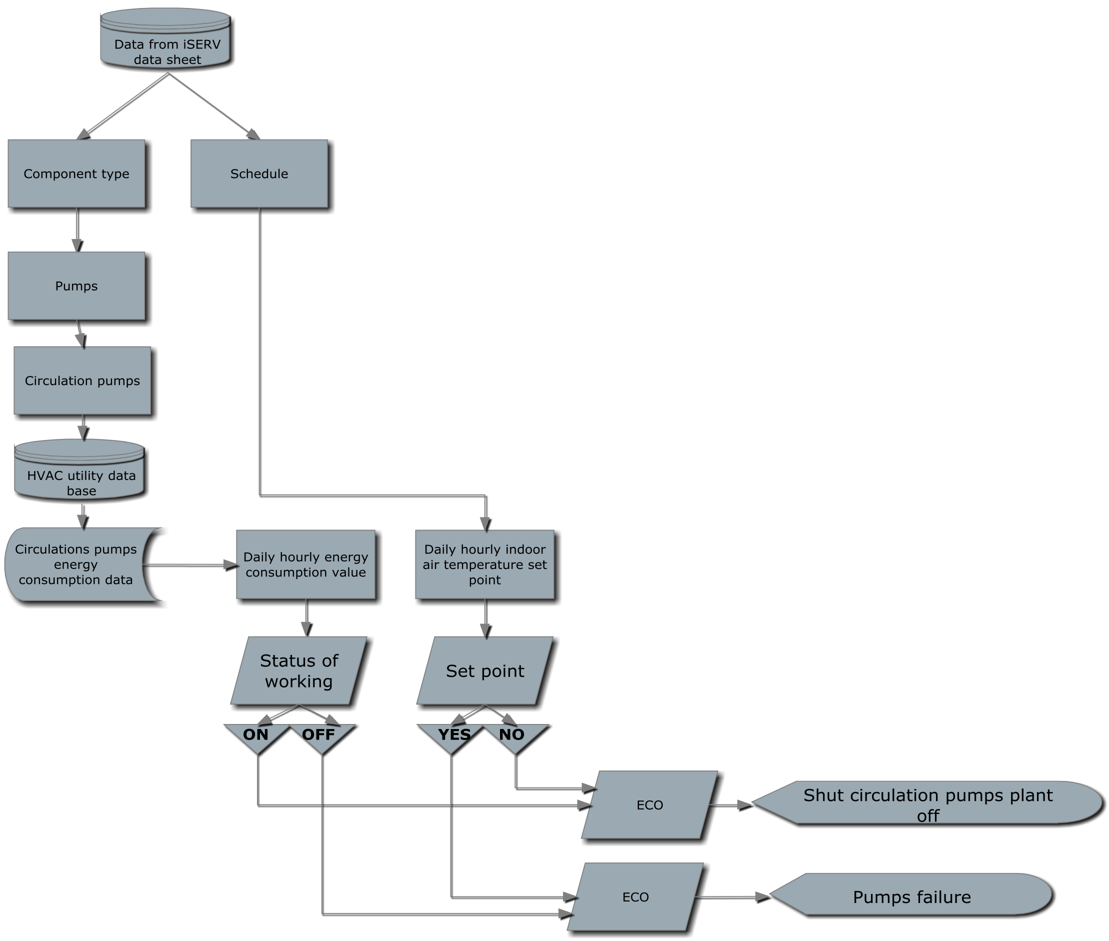
8.8.6.2 HVAC component data

- Nominal speed (rpm)
- Nominal flow rate
- Nominal electric power input

8.8.6.3 Schedule of Setpoint and Occupancy

- T - set point of indoor air temperature
- Temperature regime
- Schedule of occupancy

8.8.7 Algorithm for ECO detection



8.9 Conclusions

Some of the ECO`s are very similar to each other!

We have produced algorithms which can identify the next ECO`s:

1. P1.7 (Reduce power consumption of auxiliary equipment)
2. P2.2 (Reduce compressor power or fit a smaller compressor)
3. P3.1 (Reduce motor size (fan power) when oversized)
4. O2.2 (Shut off A/C equipment when not needed)
5. O2.3 (Shut off auxiliaries when not required)
6. O3.1 (Shut chiller plant off when not required)
7. O4.19 (Switch off circulation pumps when not required)

The objectives of these algorithms are the following:

- To prevent operation of HVAC system components (fans and pumps) outside of building schedule.
- To check the impact of pumps and fans on peak electricity load

- To alert the end-user with information about free capacity that can be used or that HVAC component is oversized.

This algorithm is already implemented into the iSERV interface and will soon be available for use. After testing it on real data we will know how to update it.

8.10 P2.13 (Consider cool storage applications (chilled water, water ice, other changing materials)

Not complete

We have made an algorithm which can identify cold storage applications (chilled water, water ice, other phase changing material)

The objective of this algorithm is to check if it is possible and reasonable to install storage system into HVAC system. It is going to be implemented into iSERV interface in two weeks.

For the next update of this algorithm we will need benchmark results from benchmarking.

We want to know what the energy consumption of buildings with and without cold storage systems is and what is a common net cooling area of buildings with cold storage systems.

We have also tested this ECO algorithm on real data obtain from iSERV data base and It was found that HVAC systems with ice-storage banks, accounting for 31% to 50% of total building electrical demand during the operating time from 07:00 to 19:00 of building. The HVAC systems without ice-storage banks accounted for 40% to 62% of total building load.

Final estimation was that with the use of this ECO we can reduce the peak building load by 15%.

8.11 P3.6 (Apply variable flow rate fan control)

Not complete

8.12 P3.7 (Consider conversion to VAV)

Not complete

8.13 P4.5 (Install variable flow rate pumping)

Not complete

The objective of these algorithms is to check the variability in the operation of HVAC system components (fans, pumps and chillers) with the coefficient of variation (CV) for the whole day and for all days of a week. For the beginning a threshold value of 16% was chosen, meaning that a CV value lower than 16% indicates that the HVAC component operates invariably (e.g. at constant air volume / speed). Before the next update the algorithm will have to tested on real data in order to determine a more suitable threshold value of CV.

8.14 O4.14 (Clean or replace filters regularly)

Not complete

The objective of this algorithm is not only to find this ECO (clean or replace filters), which is going to be implement into iSERV interface, but also to check if the position of the HVAC system's supply air duct of is suitable. To check this we will upgrade this algorithm.

The second upgrade of this algorithm will be useful for detecting the type of the metered HVAC system (CAV or VAV).

8.15 P2.3 (Split the load among various chillers)

Not complete

8.16 P2.4 (Repipe chillers or compressors in series or parallel to optimize circuiting)

Not complete

8.17 O3.3 (Operate chillers or compressors in series or parallel)

Not complete

To reduce and to optimize energy consumption of chillers the algorithm check for solution to split the load among various chiller as the difference in electricity energy consumption on the time of operation between individual chillers which is the main objective of this algorithm.

8.18 O4.2 (Perform night time ventilation)

Not complete

To reduce exist energy consumption and to improve the efficient design and operation of the air-conditioning system in night time.

The basic concept of night-time ventilation is to involve cooling the building structure overnight in order to provide a heat sink during the occupancy period. The main objective of this algorithm is to examine the possibility to implement this ECO on building.

8.19 P3.12 (Replace ducts when leaking)

Not complete

8.20 O4.6 (Eliminate air leaks (AHU, packaged systems)

Not complete

To repair or by replacing ducts with air leaks the losses are reduced and the savings are achieved which is the main objective of this algorithm.

8.21 P1.3 (Modify controls in order to sequence heating and cooling)

Not complete

8.22 O2.7 (Sequence heating and cooling)

Not complete

To reduce energy consumption of HVAC system the algorithm checks that components for heating and for cooling not operating at the same time.

8.23 O3.14 (Check (reversible) chiller stand-by losses)

Not complete

The objective of this ECO algorithm is to estimates of standby power and then on the basis of an automatic analysis will be able to offer a various techno-economic options to reduce standby power consumption.

9 Connection with the web-interface HERO (produced by K2N)

The ECO algorithms are developed using Matlab®. Each ECO algorithm consists in one Matlab® file (.m) and if necessary, some other files containing data such as .xlsx files associated to the ECO Matlab® file. The Matlab® source code is going to be built using Matlab® Builder™ NE in order to create C# source files which can be read and run by the web-interface developed by K2n.