Assessment to support the planning of sustainable data centers with high availability

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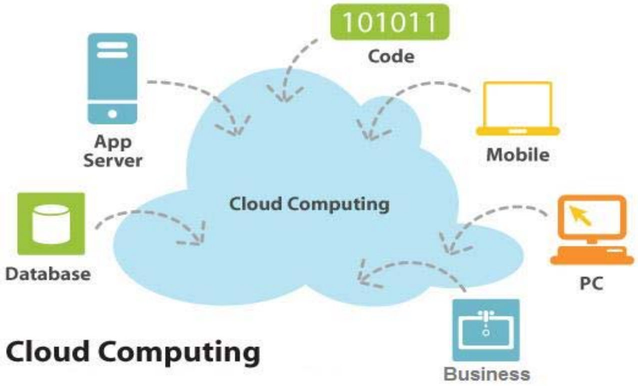
Introduction

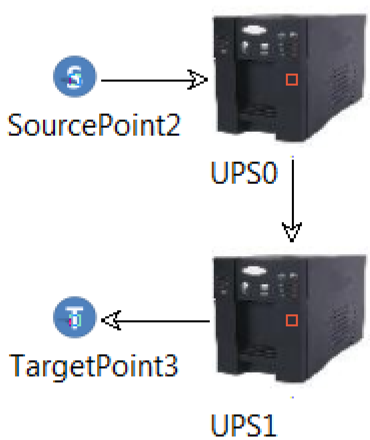
- Data centers are growing
- Fact (Considering U.S.)
  - Data centers consume about 2 % of the whole power generated .
- Concern about
  - Energy Consumption,
  - Environmental Sustainability.
- Sustainable data centers
  - Least amount of materials,
  - Least energy consumption.
- Availability
- Fault-Tolerance

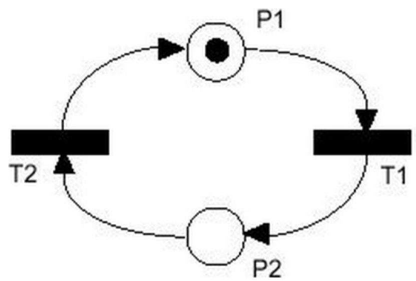


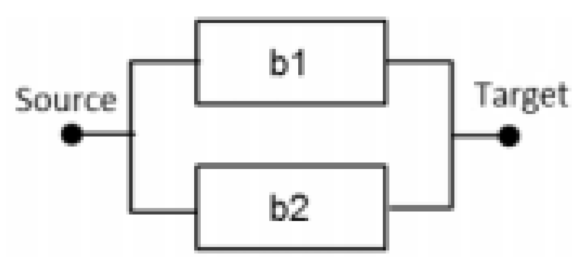
Objective

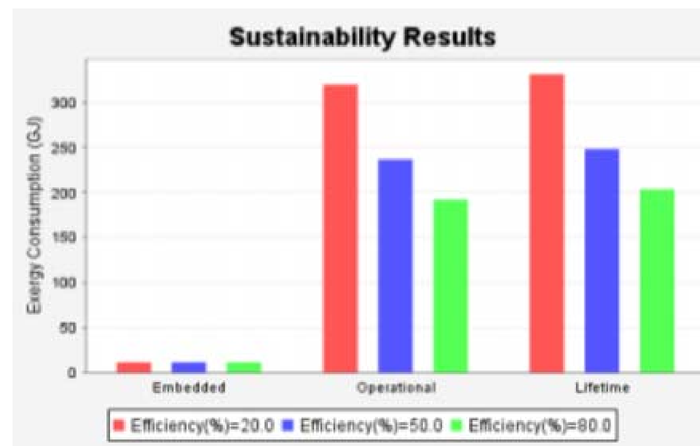
- **To provide:**
  - **Assessment to support the planning of data center power and cooling infrastructures regarding sustainability impact, dependability metrics and cost issues.**

Energy Flow Model → SPN or RBD → availability, sustainability impact, etc









Objective

- More specifically, the objectives are:
  - To **propose** a set of formal **models for** estimating **sustainability** impact, **cost** and **dependability** metrics of **power and cooling** data center infrastructures.
  - To **construct** models that represent data center **power** and **cooling** infrastructures in order to compare the results as well as to identify system parts that may be improved.
  - To **propose** data center **architectures** through Reliability Importance (**RI**)
  - To consider a **methodology** that allows data center designers to analyze the **system piecewise** as well as to combine the evaluation results

Objective

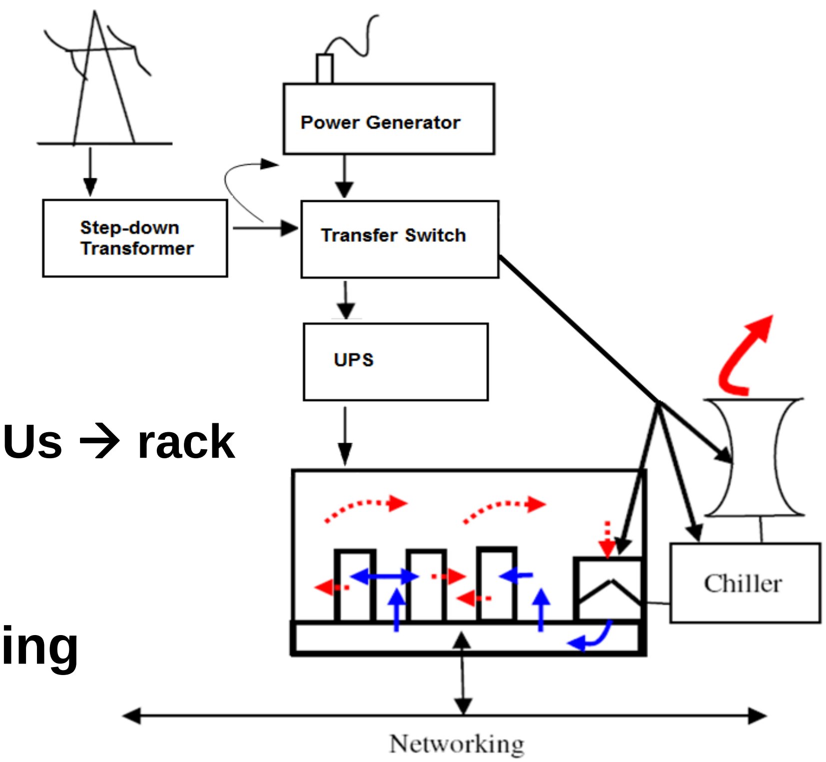
- More specifically, the objectives are:
  - **To develop a tool** that implements the above models and enables a data center designer/administrator **to estimate those metrics** without the knowledge of formal models.
  - To **quantify** the **environmental impact** adopting the metric **exergy** consumption.
  - To consider **other sustainability impacts** (e.g., **CO2 emission**, PUE) to **compare** the environmental impact of real-world data center architectures considering the **energetic mix of U.S. and Brazil**.
  - To define an **optimization** model to optimize the evaluation of data center architectures in relation to sustainability, cost and dependability issues.

Data Center Infrastructure

– IT infrastructure:
  - Servers,
  - Networking equipment,
  - Storage devices.

– **Power infrastructure:**
  - **SDT → transfer switches → UPS → PDUs → rack**

– **Cooling infrastructure:**
  - **Extracts heat → prevents overheating**
  - **CRAC, Cooling Tower, Chiller**



Metrics

- Dependability
  - Availability
  - Reliability
  - Downtime
  - Reliability Importance (RI) and RI + Acquisition Cost

- Sustainability Impact
  - Exergy Consumption
  - CO_2 Emissions

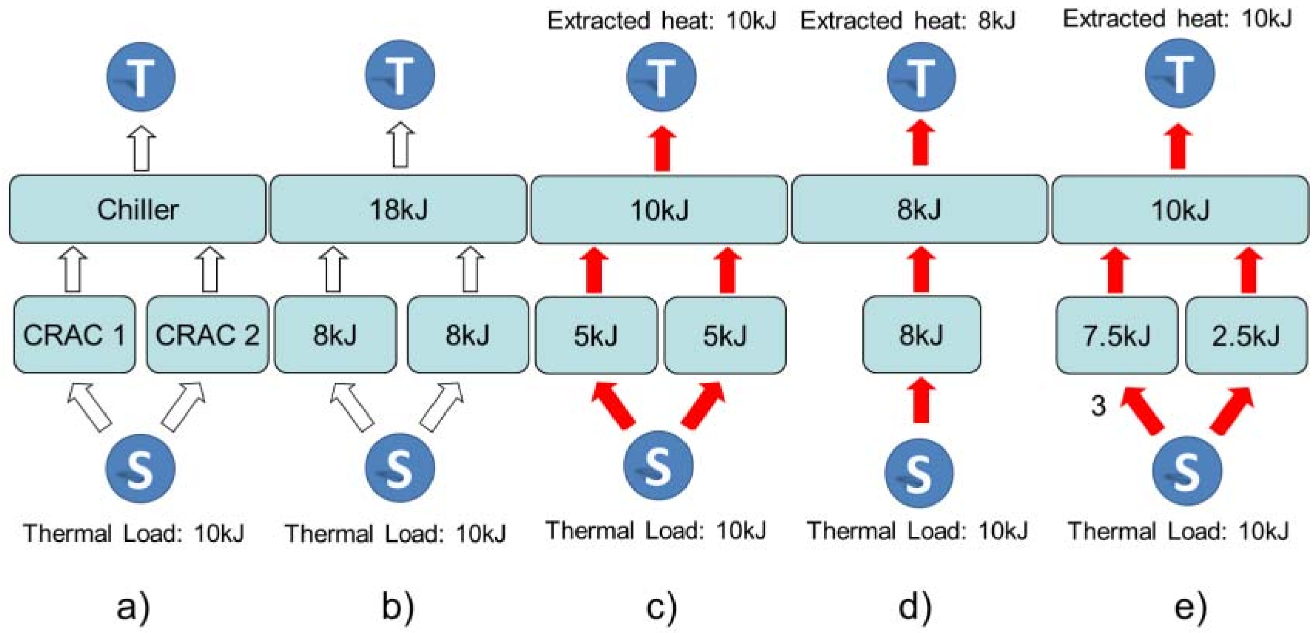
- Cost
  - Acquisition cost
  - Operational cost

Exergy

- **Energy** can **never** be **destroyed** (FLT).
- **Exergy** can be **destroyed** (SLT).
- The **exergy** destruction or **consumption** (**irreversibility**) must be appropriately **minimized** to obtain sustainable development.

- Exergy (available energy)
  - Represents the maximal theoretical portion of the energy that could be converted into work;
  - A system which consumes the least amount of exergy is often the most sustainable;
  - **Exergy** is **useful** when **measuring** the **efficiency** of an energy conversion process

- Energy Flow Model
  - The **system** under evaluation can be **correctly arranged**, **but** they **may not** be able to **meet system demand** for electrical energy or thermal load.



Energy Flow Model Definition

$G = (N, A, w, f_d, f_c, f_p, f_\eta)$, where:

- $N = \{s,\ t,\ i \mid s \in N_s,\ t \in N_t,\ i \in N_i;\ N_s,\ N_t,\ N_i \subset N\}$ represents the set of nodes (i.e., the components), in which N_s is the set of source nodes, N_t is the set of target nodes and $N_i = N \setminus (N_s \cup N_t)$ represents the set of intern nodes;
- $A \subseteq (N_s \cup N_i) \times (N_i \cup N_t)$ denotes the set of edges (i.e., the component connections);
- $w : A \rightarrow \mathbf{R}^+$ is a function that assigns weights to the edges (the value assigned to the edge $(j,\ k)$ is adopted for distributing the energy assigned to the node j to the node k according to the ratio $w(j,k)/\sum_{i \in j^\bullet} w(j,\ i)$, where $j^\bullet$ is the set of output nodes of j);
- $f_d : N \rightarrow \begin{cases} \mathbf{R}^+ & \text{if } n \in N_s \cup N_t, \\ 0 & otherwise; \end{cases}$
  is a function that assigns to each node the demanded heat to be extracted (considering cooling models) or the energy to be supplied (regarding power models);
- $f_c : N \rightarrow \begin{cases} 0 & \text{if } n \in N_s \cup N_t, \\ \mathbf{R}^+ & otherwise; \end{cases}$
  is a function that assigns each node with the respective maximum energy capacity;
- $f_p : N \rightarrow \begin{cases} 0 & \text{if } n \in N_s \cup N_t, \\ \mathbf{R}^+ & otherwise; \end{cases}$
  is a function that assigns each node (a node represents a component) with its retail price;
- $f_\eta : N \rightarrow \begin{cases} 1 & \text{if } n \in N_s \cup N_t, \\ 0 \leq k \leq 1, k \in \mathbf{R} & otherwise; \end{cases}$
  is a function that assigns each node with the energetic efficiency;

- Algorithms:
  - Verifying the energy flow
  - Quantifying Operational Exergy Consumption
  - Quantifying acquisition and operational costs

Energy Flow Model

- Algorithms:

OPERATIONAL EXERGY EQUATIONS OF DIFFERENT DEVICES.

Device	Operational Exergy Equation
Electrical	$P_{in} \times (1 - \eta)$
Diesel Generator	$P_{in} \times \left(\frac{\varphi}{\eta} - 1\right)$
CRAC	$Q_{in} \times \left(1 - \frac{T_{cold}}{T_{room}} + \frac{1}{\mu}\right)$
Chiller	$Q_{in} \times \left(\frac{1}{COP} - \frac{T_{tower} - T_{chilled}}{T_{chilled}}\right)$
Cooling Tower	$Q_{in} \times \left(1 - \frac{T_{amb}}{T_{warm}} + \frac{1}{\mu}\right)$

  - Verifying the
  - Quantifying (

$$Ex_{op} = \sum_{i=1}^{n} Ex_{op_i} \times T_{life} \times A$$

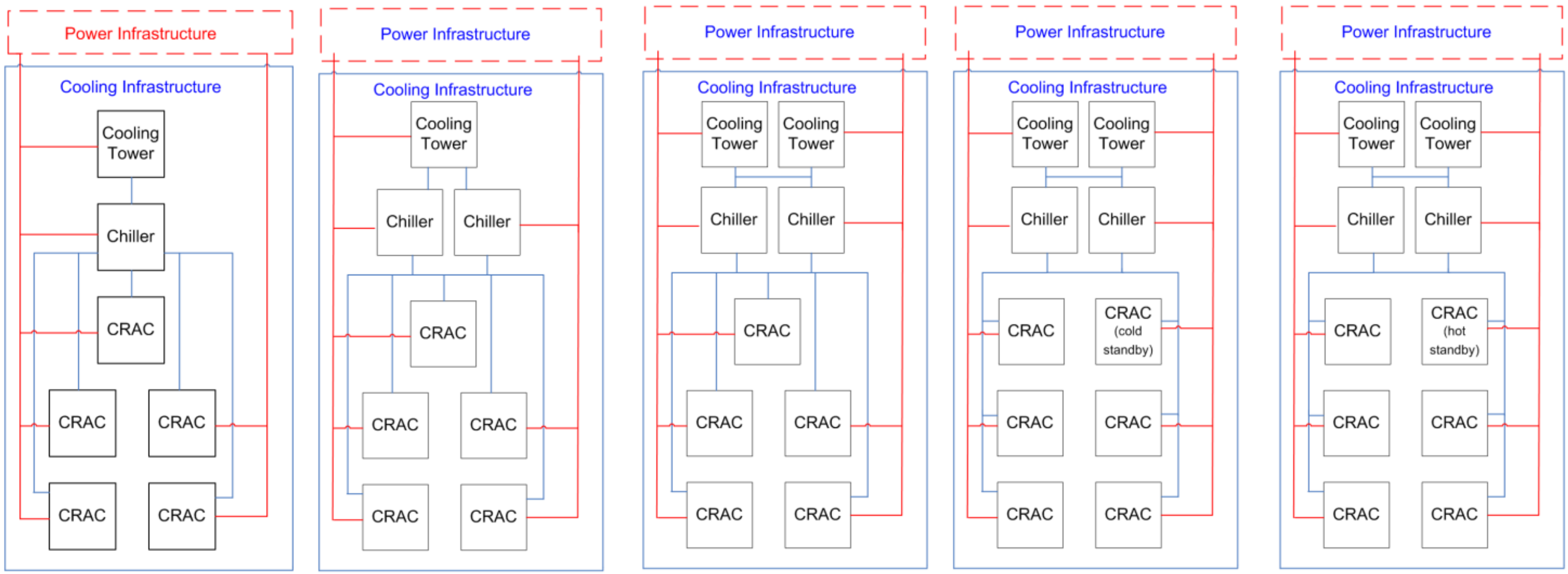
  - Quantifying acquisition and operational costs

$$OC = E_{input} \times T \times E_{cost} \times A$$

Case Study

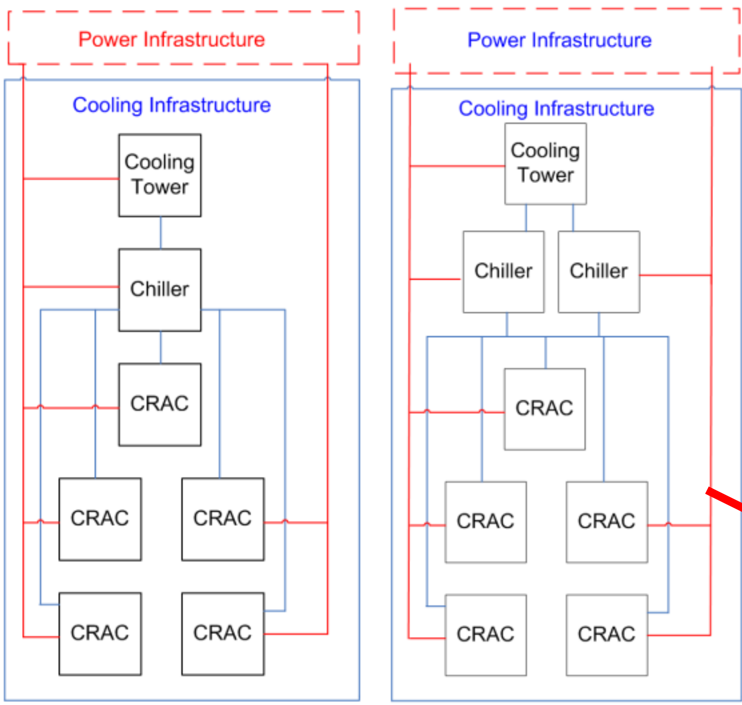
- From a baseline data center cooling infrastructures, we propose 4 architectures.
- Reliability Importance.
- For each architecture, we estimate:
  - (i) availability;
  - (ii) the sustainability impact and
  - (iii) the acquisition and operational costs.

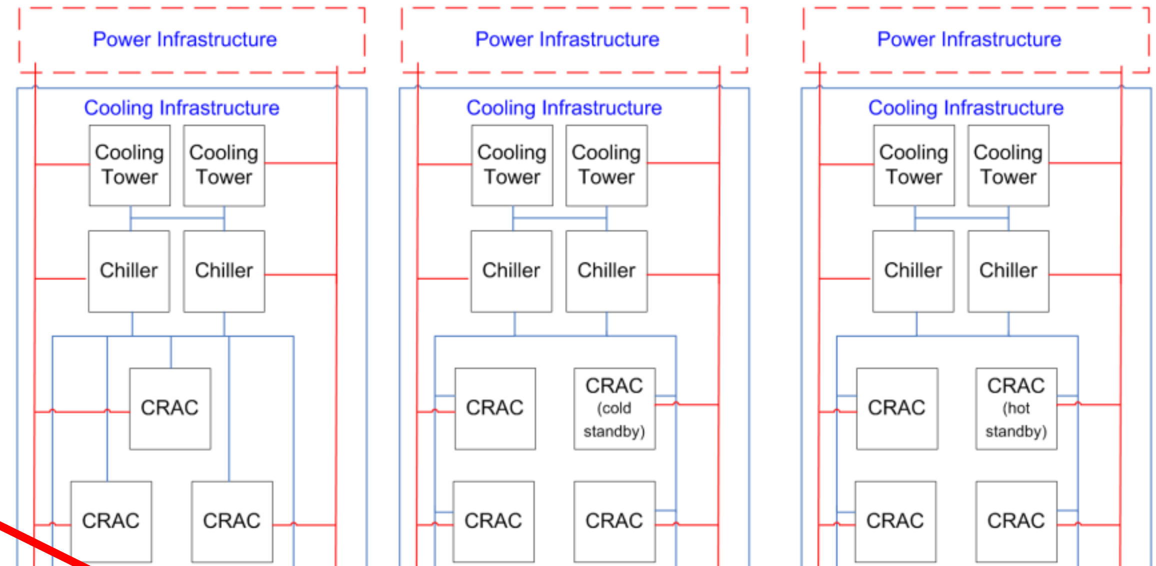
Cooling Architectures



C1 C2 C3 C4 C5

Cooling Architectures



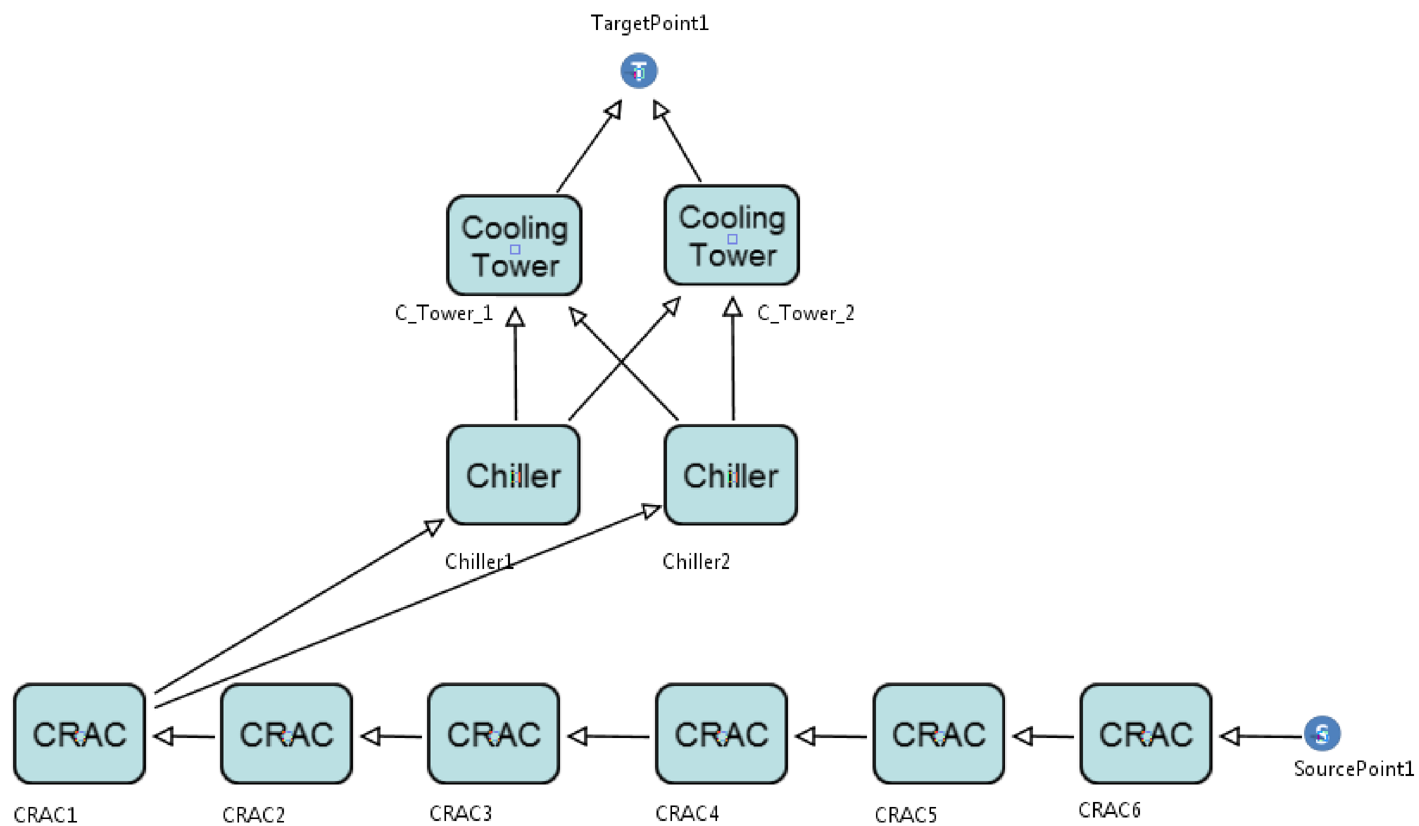


C1 C2

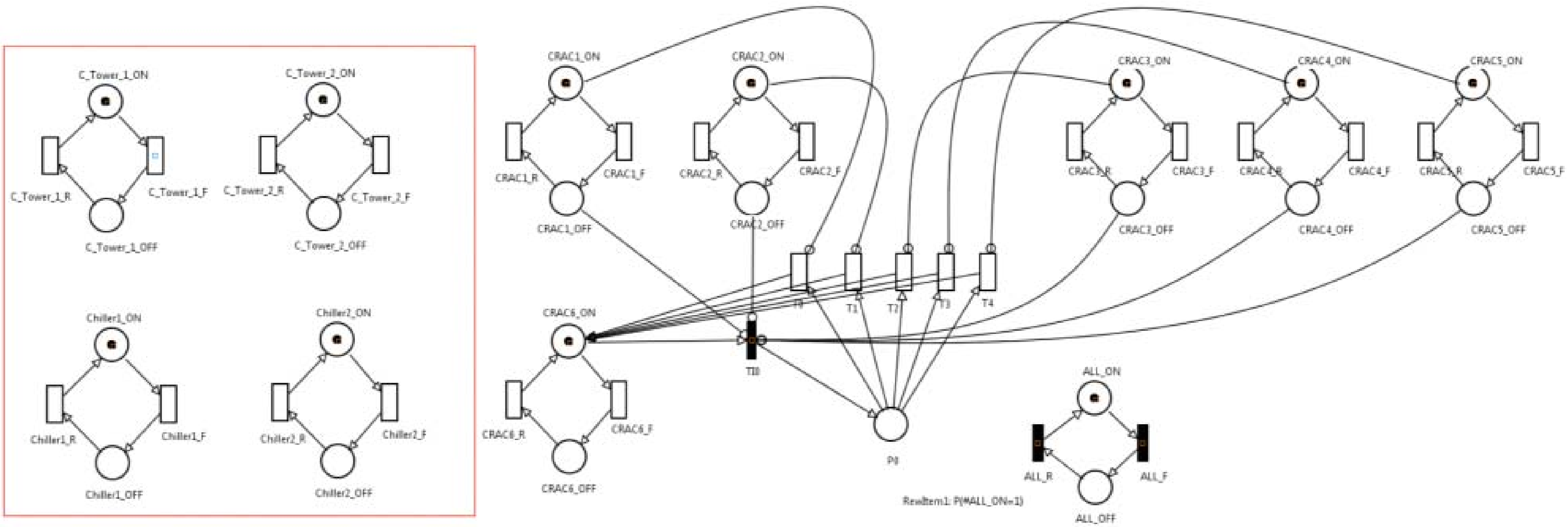
Architecture	Chiller	Cooling Tower	CRAC
C1	0.22	0.19	0.17
C2	0.08	0.26	0.23
C3	0.10	0.08	0.30

Energy Flow Model

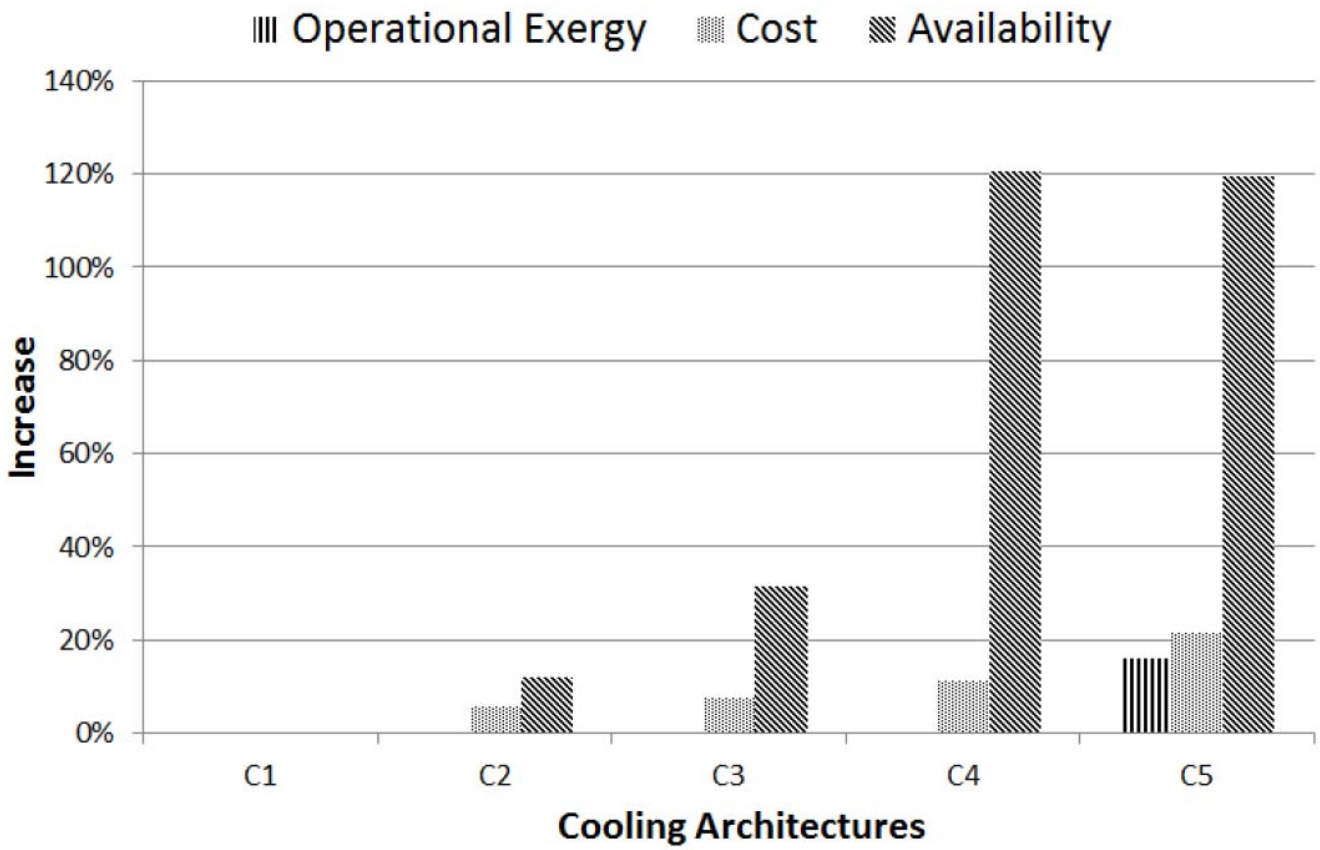
- Architecture C4



SPN model - Architecture C4



- Results



Operational Exergy
Cost
Availability
140%
120%
100%
80%
60%
40%
20%
0%
Increase
C1
C2
C3
C4
C5
Cooling Architectures

Conclusion

- Presented:
  - a set of formal models to estimate the availability, cost and sustainability impacts of data center infrastructures.
  - reliability importance index to propose architectures with higher availability.
  - Experiments demonstrated the applicability of the proposed approach.

- As a future work:
  - to analyze other scenarios
  - to apply optimization techniques.
  - to compare environmental impacts of data center architectures considering the energetic mix of U.S., Brazil and Germany.

MoDCS

Thanks!