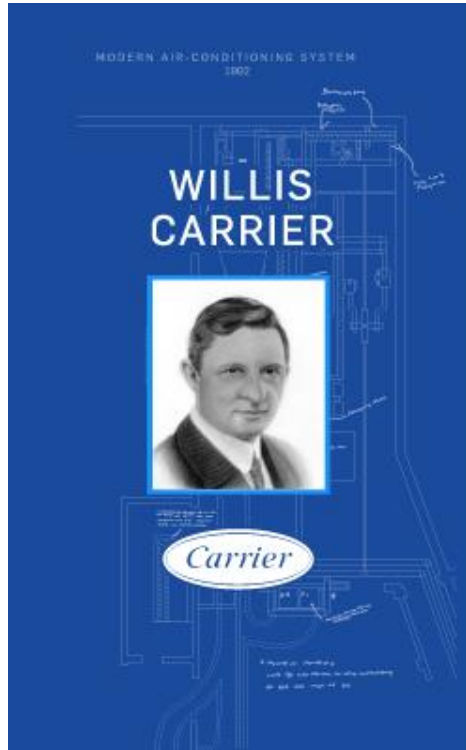A brief introduction to

CARRIER

Master thesis opportunities

Johan Åkesson, Clas Jacobson
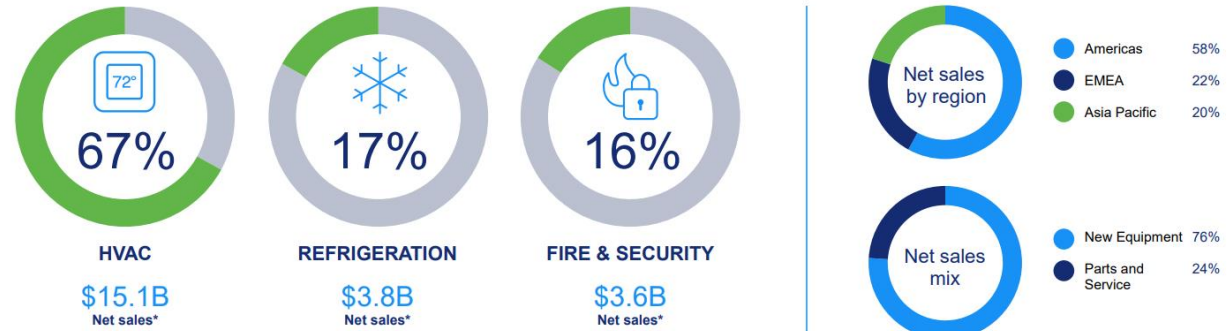
Carrier – Then and Now

WILLIS CARRIER

MODERN AIR-CONDITIONING SYSTEM

Carrier

Our Business

2023 Net Sales Breakdown

67%	17%	16%
HVAC	**REFRIGERATION**	**FIRE & SECURITY**
$15.1B Net sales*	$3.8B Net sales*	$3.6B Net sales*

Net sales by region
- Americas 58%
- EMEA 22%
- Asia Pacific 20%

Net sales mix
- New Equipment 76%
- Parts and Service 24%

$22.1B 2023 NET SALES

~53,000 EMPLOYEES

75+ BRANDS

100+ NEW PRODUCTS for the 9th consecutive year

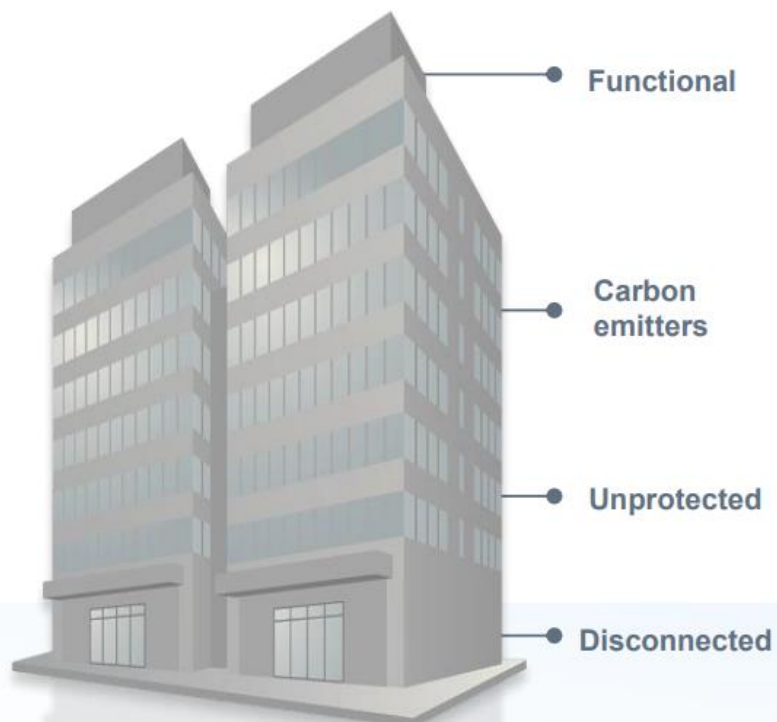* Segment sales include intercompany sales.

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Read in conjunction with Form 10-K. 12/31/2023

4

- 1902: Invents the modern air-conditioning system

- 1915: Founds Carrier Corporation

- Today: A world leader in healthy, safe, sustainable and intelligent building and cold chain solutions

- 2022: Opened small engineering office in Lund

Carrier

Environmental Trendsetter

BUILDINGS OF YESTERDAY

- Functional
- Carbon emitters
- Unprotected
- Disconnected

BUILDINGS OF TOMORROW

- HEALTHY
- SUSTAINABLE
- SAFE
- INTELLIGENT

People spend **~90%** of our time indoors[1]

Indoor air can be **3-5x** more polluted than outdoor air[1]

Buildings account for **~40%** of greenhouse gas emissions[2]

1 in 5 existing buildings retrofitted to meet net-zero emissions by 2050[2]

Effective filtration can eliminate **99%** of airborne pathogens[3]

<30% of U.S. homes protected to National Fire Protection Association standards[4]

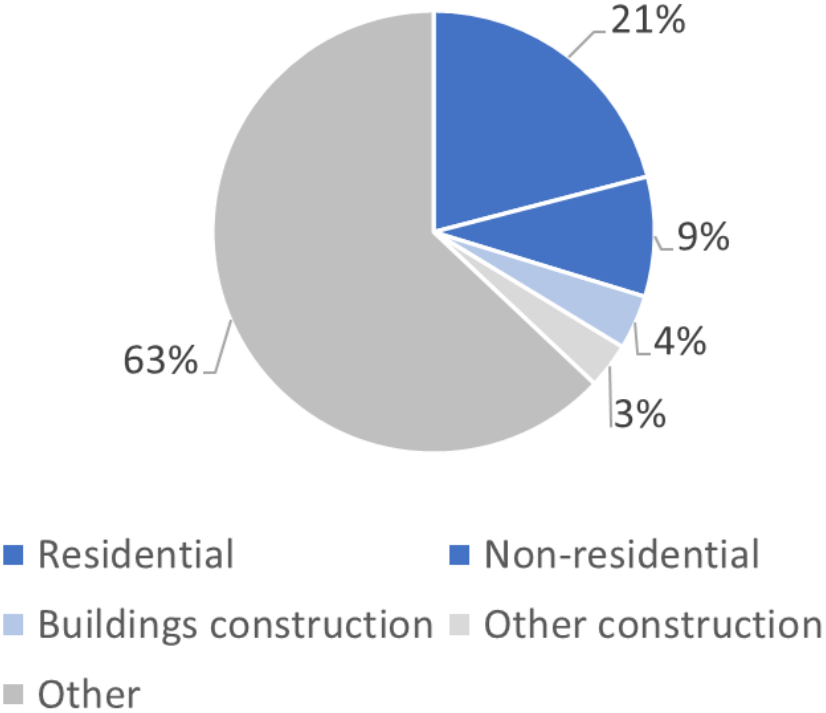**>4 billion** connected IoT devices in commercial buildings by 2028[5]

Integrated smart building systems can reduce energy use **~10%-20%**[6]
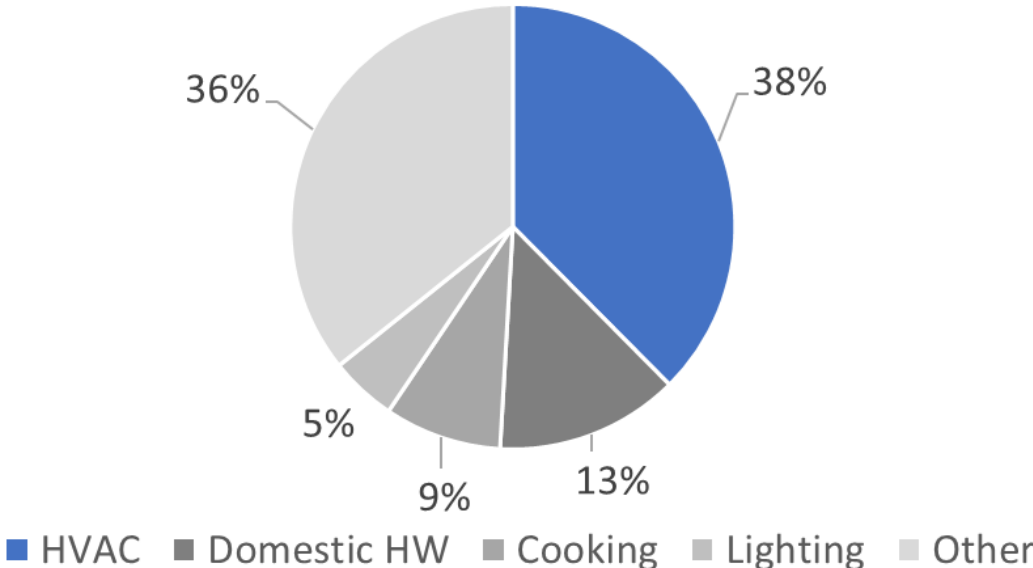
Carrier

1. Harvard School of Public Health | 2. IEA | 3. Carrier product legal claim, based on third-party testing (2020)
4. NFPA | 5. Deloitte, Gartner | 6. The Nesler Group, National University of Singapore

Building Energy Challenge

Buildings Final Global Energy Consumption 2022

Legend:
■ Residential ■ Non-residential
■ Buildings construction ■ Other construction
■ Other

Buildings Energy Global Consumption 2020

Legend:
■ HVAC ■ Domestic HW ■ Cooking ■ Lighting ■ Other

Building operation consume *30% energy worldwide*

https://www.iea.org/energy-system/buildings

Heating, Ventilation and Air Conditioning consumes *38% of building operation energy*

https://www.sciencedirect.com/science/article/pii/S235248472101427X

Technology Trendsetter

- 20 years of Modelica modeling maturity
- Python, Jupyter notebooks, computations
- On-going collaboration with open-source state-of-art computational tool development (experts & their tools)
- Labs & facilities to test new ideas
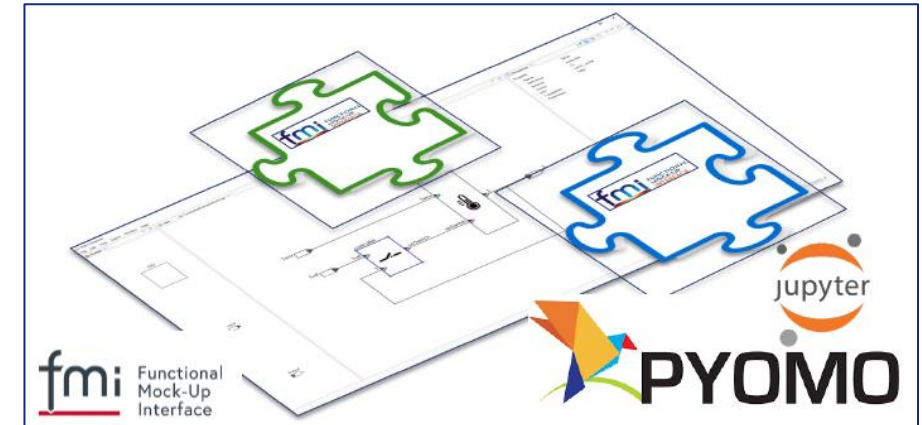
Energy Modeling and Learning in Building Systems

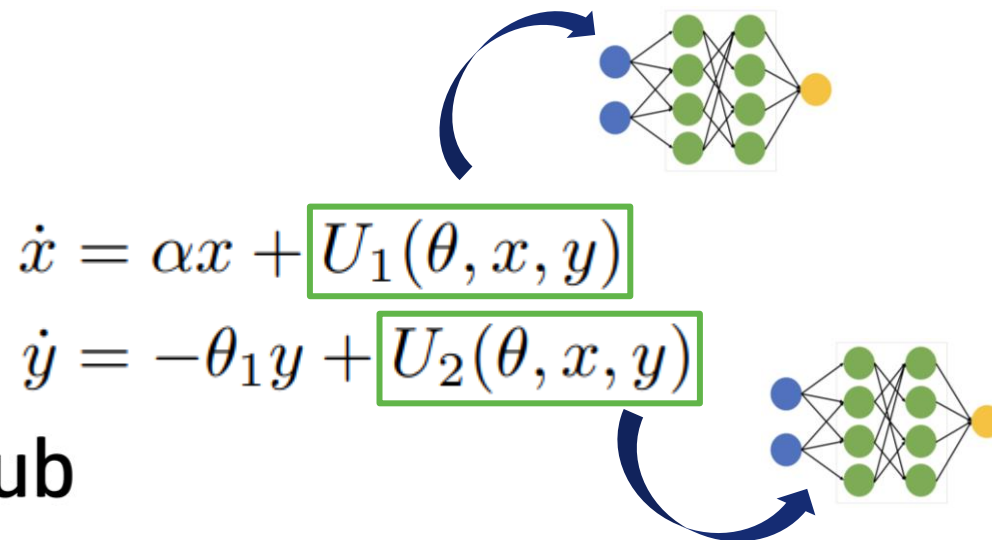- Buildings are complex: heterogeneous physical domains, large scale, span a large range of time constants

- Energy models are required to predict and optimize energy consumption in buildings including data centers

- Physics (still) matter (in the era of machine learning) and need to be combined with measurement data

Modeling is expensive and requires experts – Need learning and automation!

NEUROMANCER
Scientific Machine Learning

https://github.com/pnnl/neuromancer

$$\dot{x} = \alpha x + \boxed{U_1(\theta, x, y)}$$

$$\dot{y} = -\theta_1 y + \boxed{U_2(\theta, x, y)}$$

JuliaHub

Carrier

arXiv > cs arXiv:2403.12938
Computer Science > Machine Learning
[Submitted on 19 Mar 2024]
Neural Differential Algebraic Equations
James Koch, Madelyn Shapiro, Himanshu Sharma, Draguna Vrabie, Jan Drgona

arXiv > cs arXiv:2001.04385
Computer Science > Machine Learning
[Submitted on 13 Jan 2020 (v1), last revised 2 Nov 2021 (this version, v4)]
Universal Differential Equations for Scientific Machine Learning
Christopher Rackauckas, Yingbo Ma, Julius Martensen, Collin Warner, Kirill Zubov, Rohit Supekar, Dominic Skinner, Ali Ramadhan, Alan Edelman

MPC and Estimation for Data Center Energy Savings

- Buildings are complex: heterogeneous physical domains, large scale, span a large range of time constants and dynamics is highly coupled

- Supervisory control of a thermal cooling system cannot be tuned in the lab – need models and model-based verification

- Model-predictive control and state/parameter estimation is emerging in the building industry – not yet standard practice (data centers are safety-critical systems

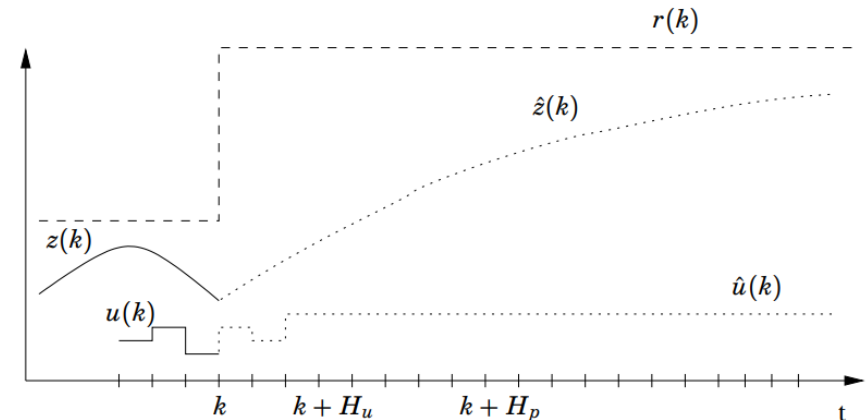*10-20% energy savings are possible with great supervisory controls!*
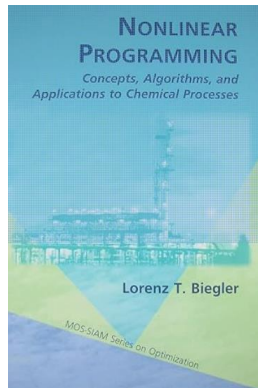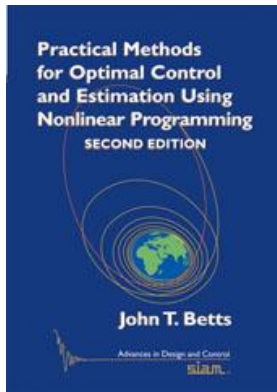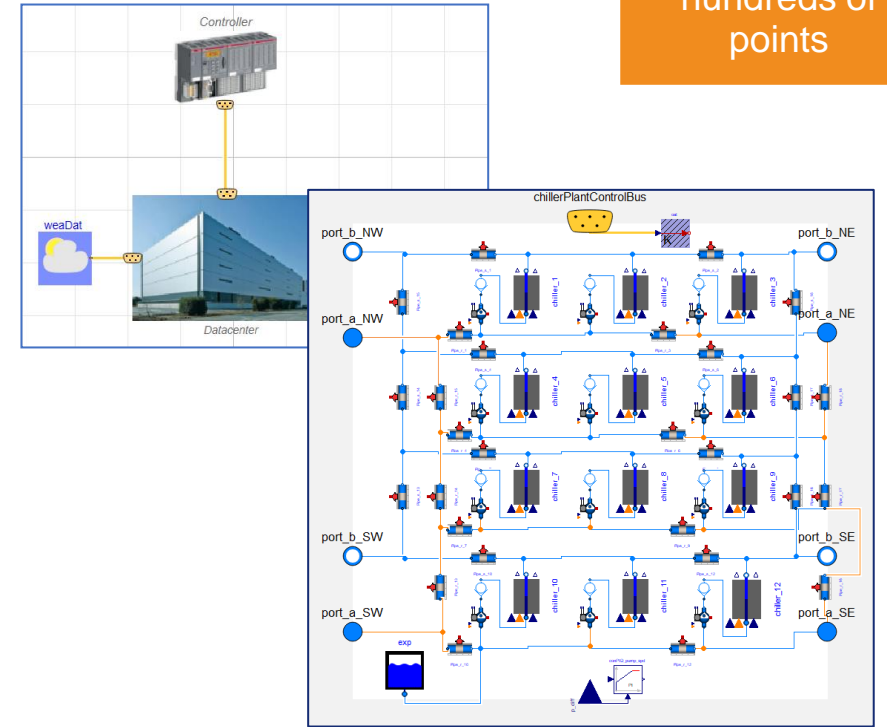
$$\min \int_{t_0}^{t_f} L(x, u, p) dt$$

$$s.t. \quad \dot{x} = f(x, u, p), x(0) = x_0$$

$$h(x, u, p) = 0$$

$$g(x, u, p) \leq 0$$

$$x(t) \in R^{n_x} \quad u(t) \in R^{n_u} \quad p \in R^{n_p}$$

7

Master Thesis Projects - Logistics

- Supervisors:

  - Johan Åkesson (johan.akesson1@carrier.com)
  - Clas Jacobson (clas.jacobson2@carrier.com)
  - Viktor Linders (viktor.linders@carrier.com)

- Local office location:
  - Ideon Gateway office hotel, 4th floor: desks & coffee available

- Opportunity: Learn from Carrier engineers to solve relevant problems

- Long-standing collaboration with the Department of Automatic Control

- Control design methods and architectures, machine learning…

- Joint advising of Master's students and PhD students