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# **THERMAL PREDICTION FOR IMMERSION COOLING DATA CENTERS BASED ON RECURRENT NEURAL NETWORKS**

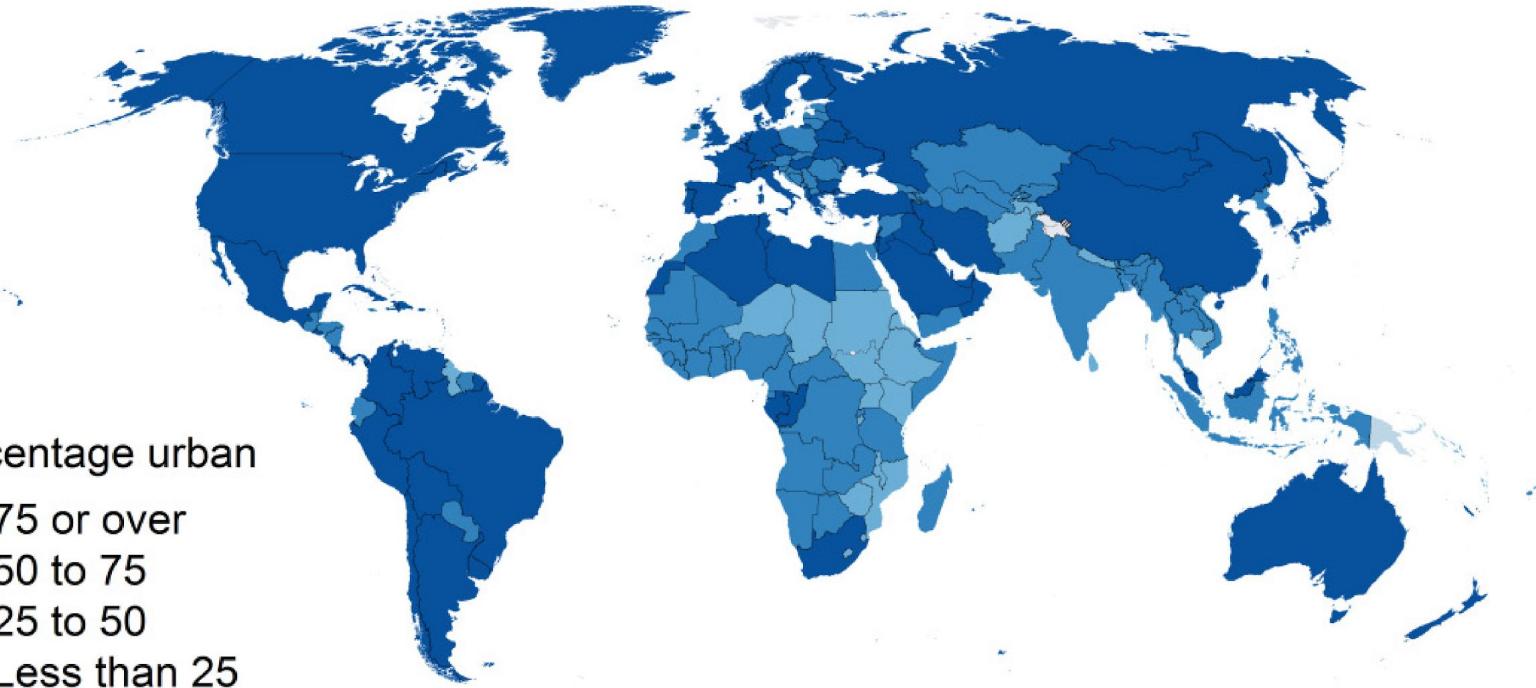
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2050

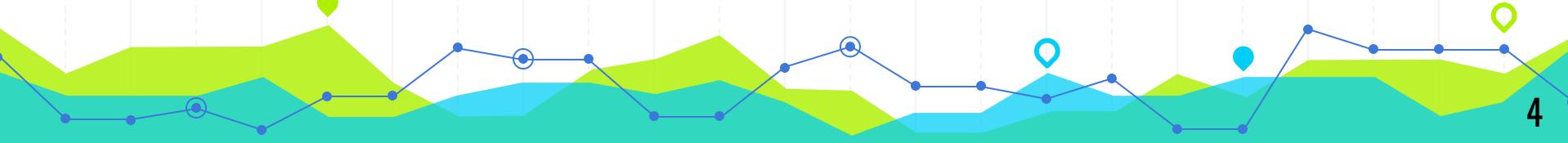
Percentage urban

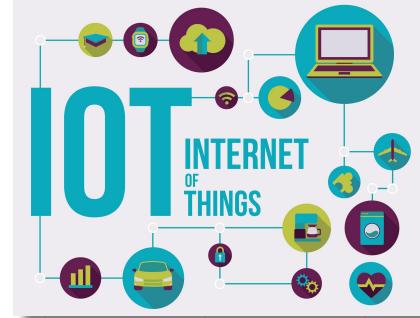
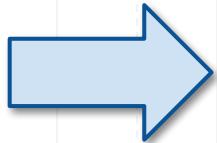
- 75 or over
- 50 to 75
- 25 to 50
- Less than 25
- No data



Source: United Nations, UN







100.000.000.000 IoT  
Devices in 2030

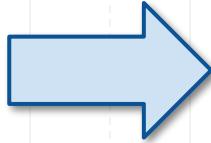




How will we process this  
large amount of data?

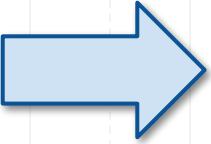


# CL<sup>W</sup>UD COMPUTING



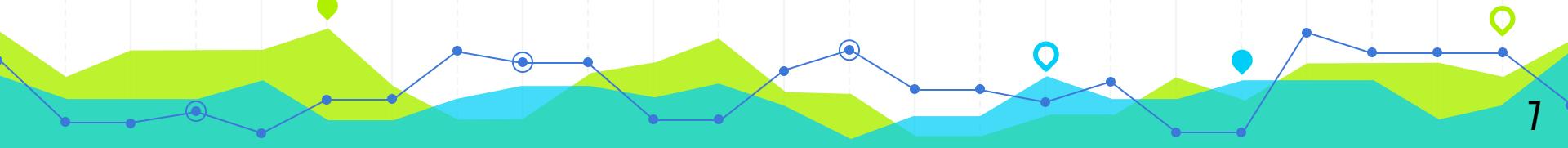
- Network saturation
- High latencies
- E.g. Self-driving car reaction time at 100 Km/h
  - ↳ Cloud: 2.5 **m** (~100 ms)
  - ↳ Edge: 2.5 **cm** (~10 ms)

# EDGE COMPUTING



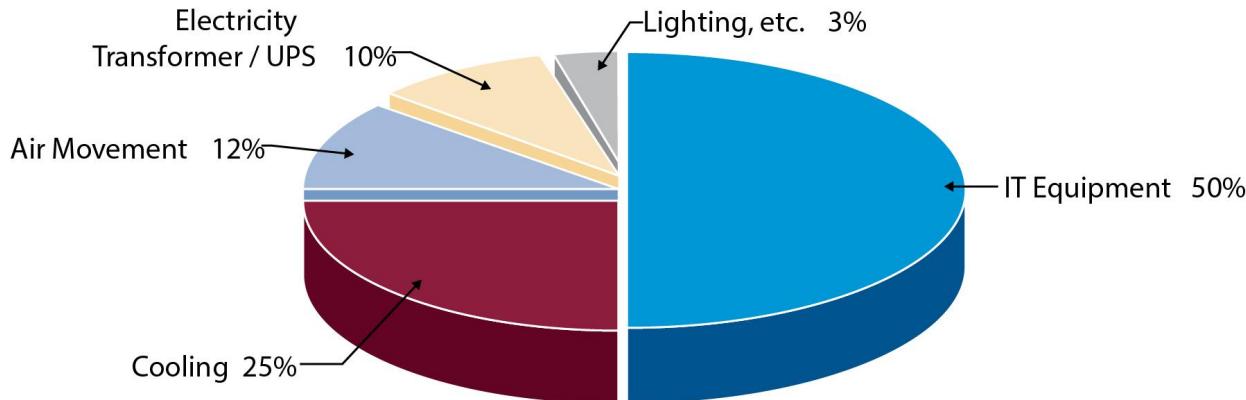
## Main challenges:

- Climate-Independent cooling
- Reduce energy consumption
- Reduce area (Power Density)



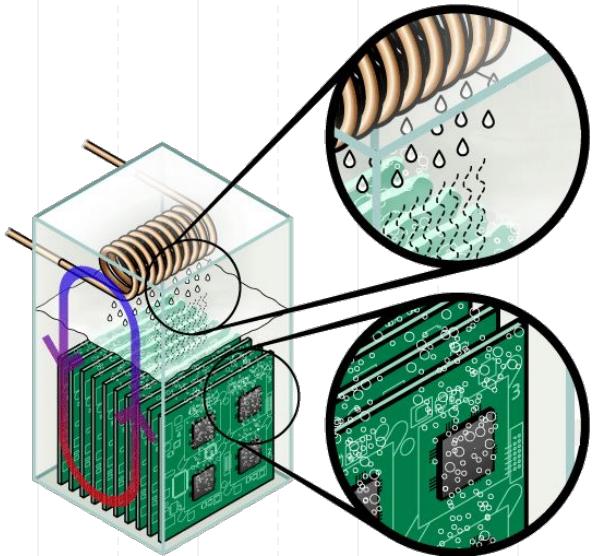
# ENERGY BREAKDOWN OF DATA CENTERS

**Cooling Energy ≈ 40%**



Source: EYP Mission Critical Facilities Inc.

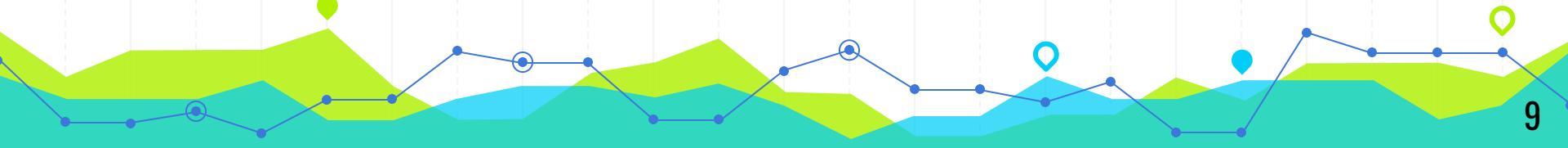
# TWO-PHASE PASSIVE IMMERSION COOLING IN HYDRO-FLUORO-ETHERS



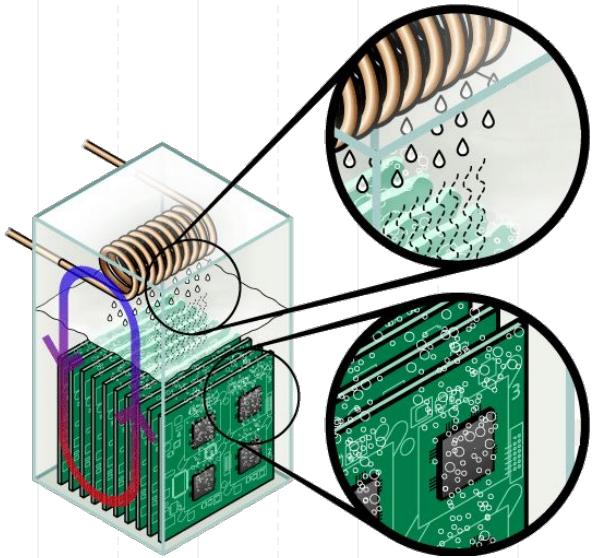
**3M**  
Novec

- Climate independent cooling
- Passive cooling
- High power density

↳ From 40 kW to 250 kW  
↳ Reduce area

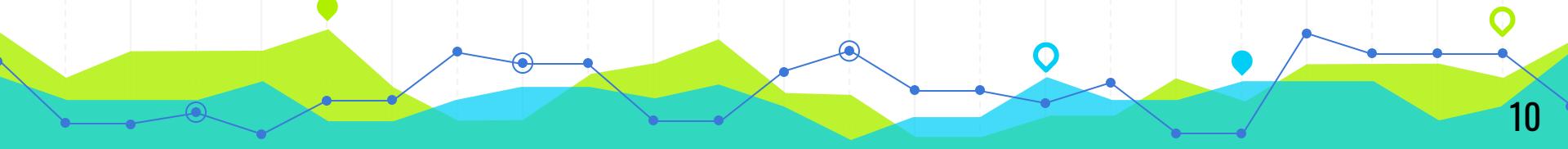


# TWO-PHASE PASSIVE IMMERSION COOLING IN HYDRO-FLUORO-ETHERS



**3M**  
Novec

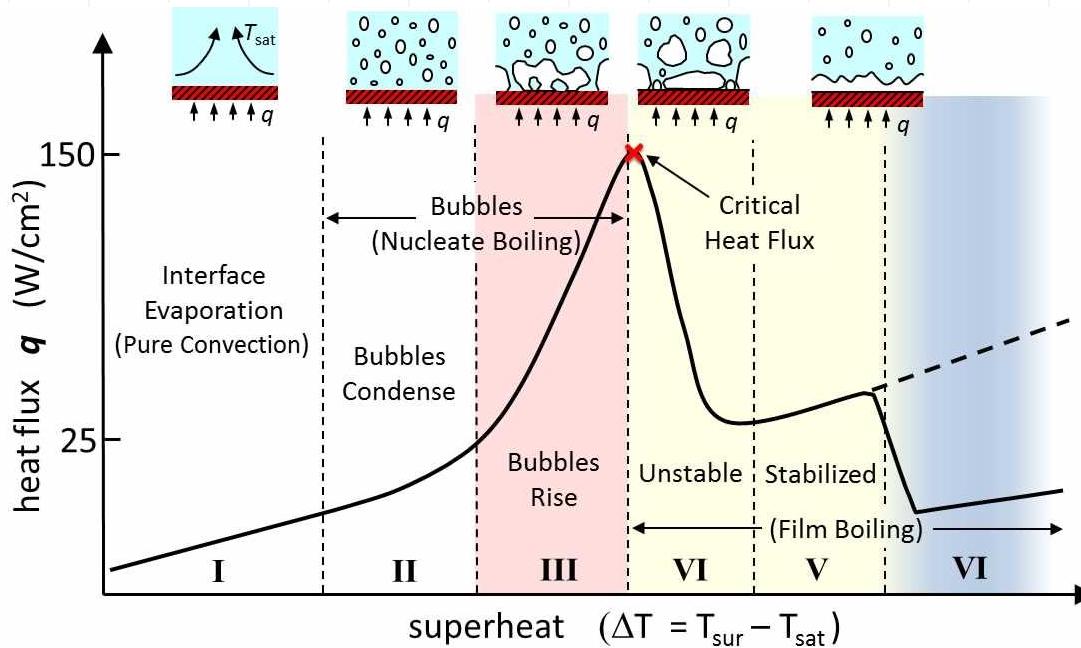
- How can we protect devices from critical temperatures?
- How can we optimize it?



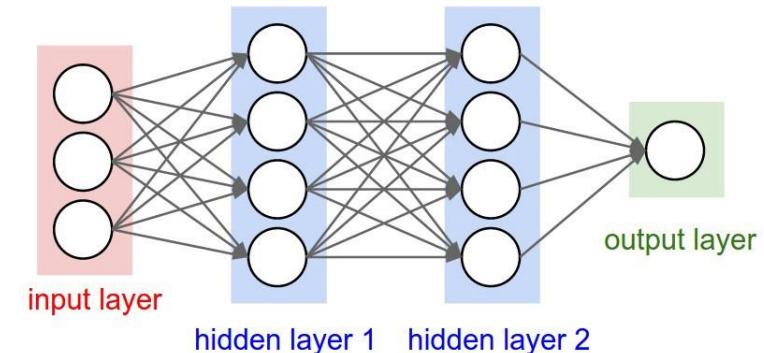
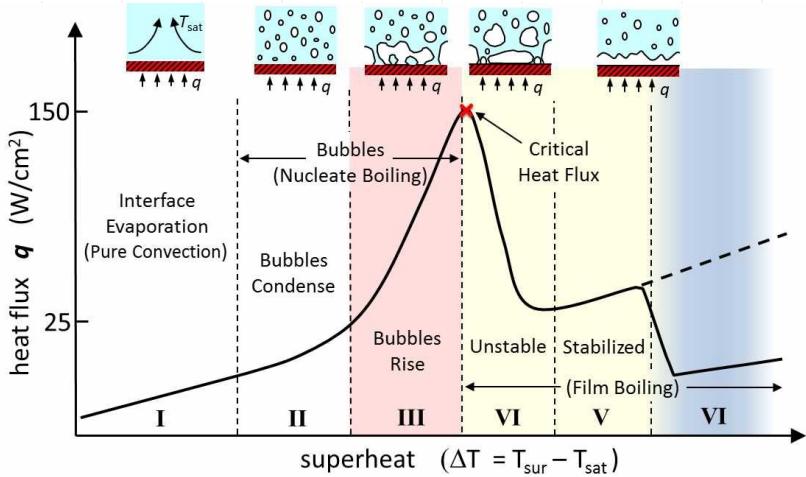
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# EFFICIENCY AND SAFETY



# EFFICIENCY AND SAFETY



Predictive models of CPU temperature using neural networks



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# WHY RECURRENT NEURAL NETWORKS?

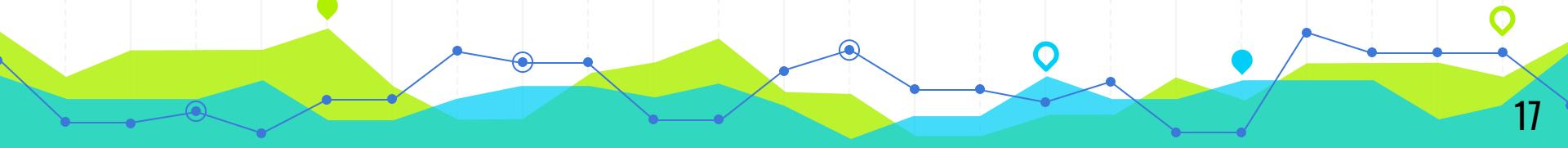
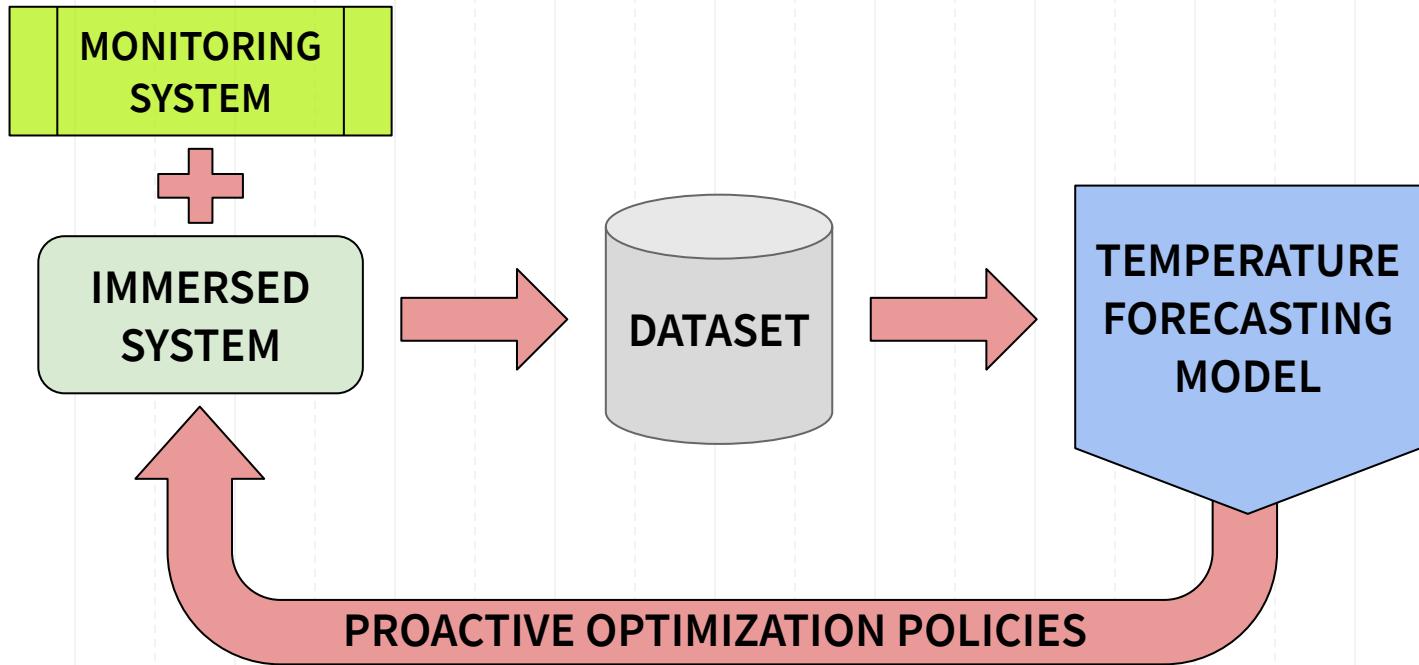
- Able to **learn** complex **non-linear relations** between features
- Native support
  - ↳ Data in **time series** form
  - ↳ **Multiple inputs** and outputs
  - ↳ **Multi-step** forecasting
- Easy deployment with **Tensorflow + Keras**



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# METHODOLOGY



# PROTOTYPE CLUSTERS OF RASPBERRY PI 3 MODEL B+

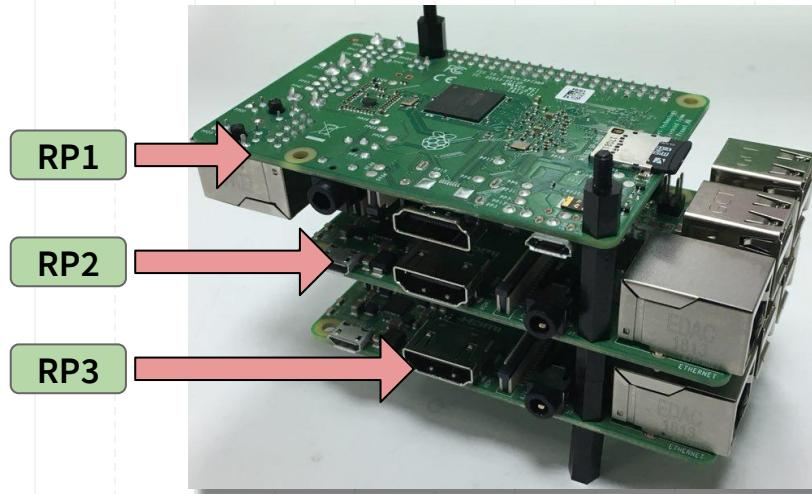


# MONITORING SYSTEM

## COLLECTD & GRAPHITE

Selected metrics:

- Temperature (RP1)
- Temperature (RP2)
- CPU Utilization (RP2)
- CPU Frequency (RP2)
- Temperature (RP3)



Workload: Data Analytics



# MODEL EVALUATION METRICS

## Mean Absolute Error

$$MAE = \frac{1}{n} \sum_{j=1}^n |y_j - x_j|$$

## Coefficient of Determination

$$R^2 = \frac{\sum_{j=1}^n (y_j - \bar{x}_j)^2}{\sum_{j=1}^n (y_j - \bar{y}_j)^2}$$



## Standard Deviation

$$STD = \sqrt{\frac{1}{n} \sum_{j=1}^n (y_j - \mu)^2}$$

## Root Mean Square Deviation

$$RMSD = \sqrt{\frac{1}{n} \sum_{j=1}^n (y_j - x_j)^2}$$

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# EXPERIMENTS METHODOLOGY

## TENSORFLOW + KERAS

### Base Model

- ↳ Optimizer: Nadam
- ↳ Loss Function: MAE
- ↳ Time-Step: 1 min

### Optimized Model (Fully Connected, LSTM, GRU)

#### Set Architecture

- ↳ N. Layers
- ↳ N. Neurons

#### Optimize Train

- ↳ Batch Size
- ↳ Epochs
- ↳ Activation function

#### Test

# FULLY CONNECTED NETWORK

Neural Architecture	Batch Size	Epochs	MAE ± STD (°C)	RMSD (°C)	R <sup>2</sup> (%)
3 layers: 16 - 32 - 16	65	80	$1.11 \pm 1.14$	1.588	71.925
2 layers: 16 - 8	65	80	$1.13 \pm 1.08$	1.562	72.824
1 layer: 256	65	80	$1.09 \pm 0.83$	1.371	79.071
<b>1 layer: 256</b>	<b>95</b>	<b>140</b>	<b><math>0.84 \pm 0.84</math></b>	<b>1.187</b>	<b>83.897</b>



# LSTM NETWORK

Neural Architecture	Batch Size	Epochs	MAE ± STD (°C)	RMSD (°C)	R <sup>2</sup> (%)
3 layers: 8 - 4 - 2	65	80	$0.95 \pm 1.13$	1.475	75.782
2 layers: 1 - 1	65	80	$1.02 \pm 0.82$	1.311	80.871
1 layer: 2	65	80	$0.91 \pm 0.89$	1.270	82.044
<b>1 layer: 2</b>	<b>95</b>	<b>210</b>	<b><math>0.71 \pm 0.66</math></b>	<b>0.969</b>	<b>87.527</b>

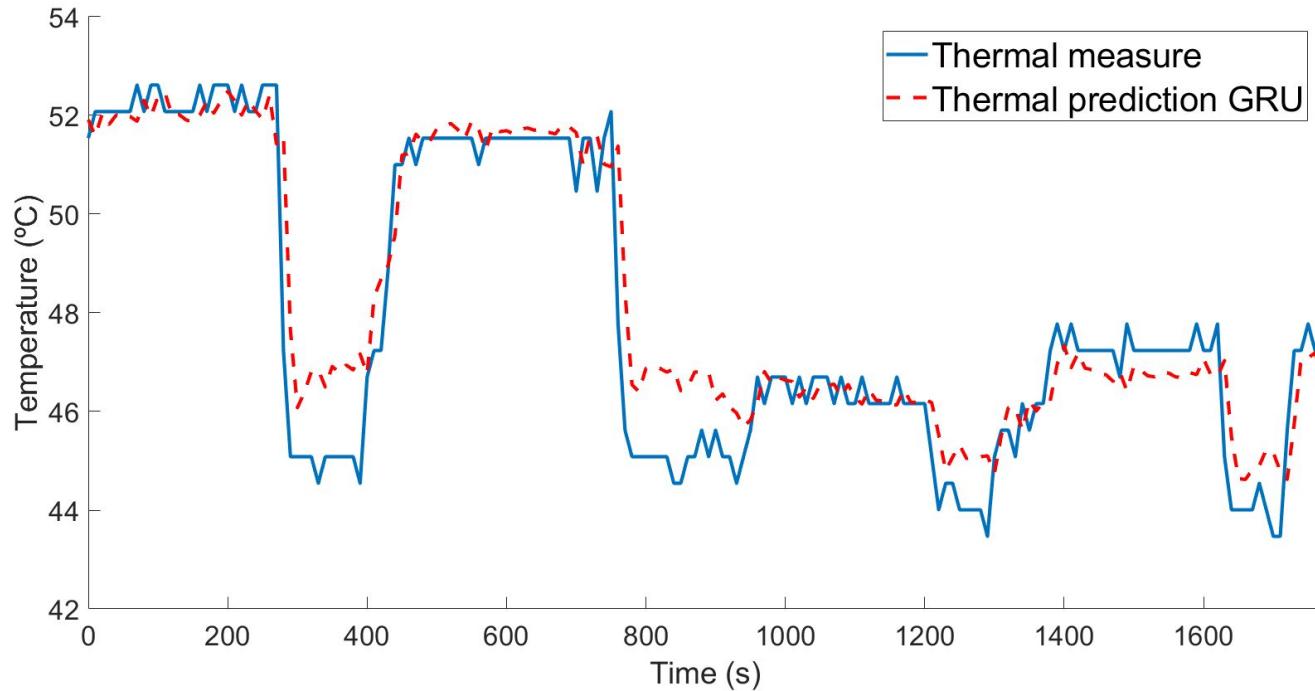


# GRU NETWORK

Neural Architecture	Batch Size	Epochs	MAE ± STD (°C)	RMSD (°C)	R <sup>2</sup> (%)
3 layers: 4 - 2 - 1	65	80	0.81 ± 0.83	1.157	82.211
2 layers: 4 - 2	65	80	0.85 ± 0.78	1.150	82.429
1 layer: 4	65	80	0.74 ± 0.68	1.002	86.668
<b>1 layer: 4</b>	<b>95</b>	<b>120</b>	<b>0.75 ± 0.59</b>	<b>0.957</b>	<b>89.539</b>



# GRU NETWORK



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# CONCLUSIONS

- **Temperature forecasting model** (1 min) using GRU neurons
  - ↳  $\text{MAE} \pm \text{STD} = 0,75 \pm 0,59 \text{ }^{\circ}\text{C}$ ,  $\text{RMSD} = 0.957 \text{ }^{\circ}\text{C}$ ,  $R^2 = 89,539 \%$
- Allows the development of automatic and online models
  - ↳ Minimize human assistance
- Solution for the **deployment of Edge Data Centers** in urban areas
  - ↳ Climate independent cooling
  - ↳ Cooling energy  $\approx 1\%$
  - ↳ Highly optimized systems

# FUTURE DIRECTIONS

**3M** Science.  
Applied to Life.™

**Adam**  
Your datahome



**aeon**  
ingeniería

**ETSIIT**  
ESTADO DE SUPERIOR DE TECNOLOGÍAS DE TELECOMUNICACIÓN  
**UPM**  
UNIVERSIDAD POLITÉCNICA DE MADRID



# THANK YOU FOR YOUR ATTENTION!

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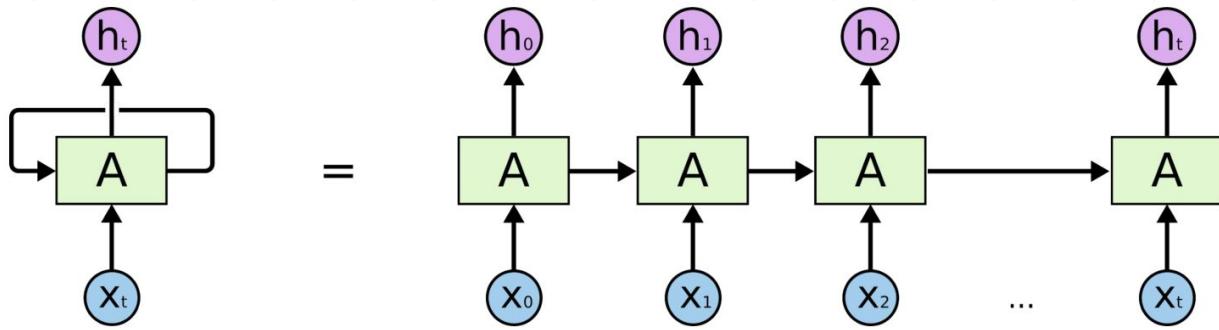


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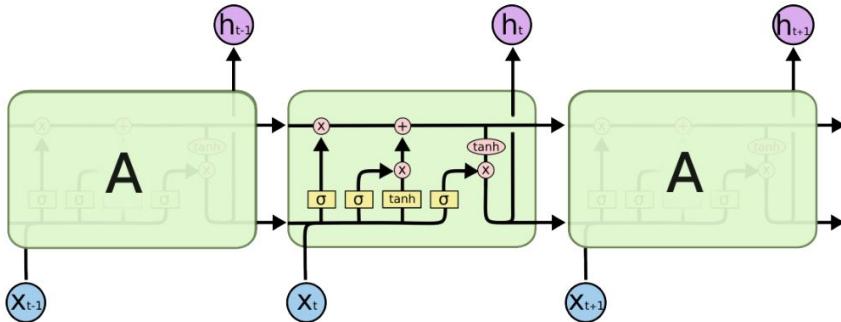


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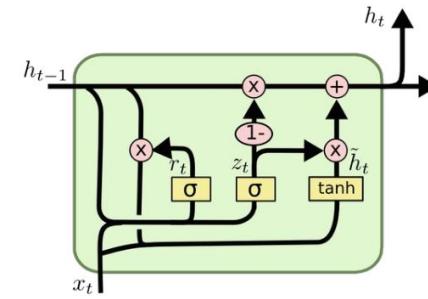




1.a. Simple RNN neuron



1.b. LSTM neuron



1.c. GRU neuron

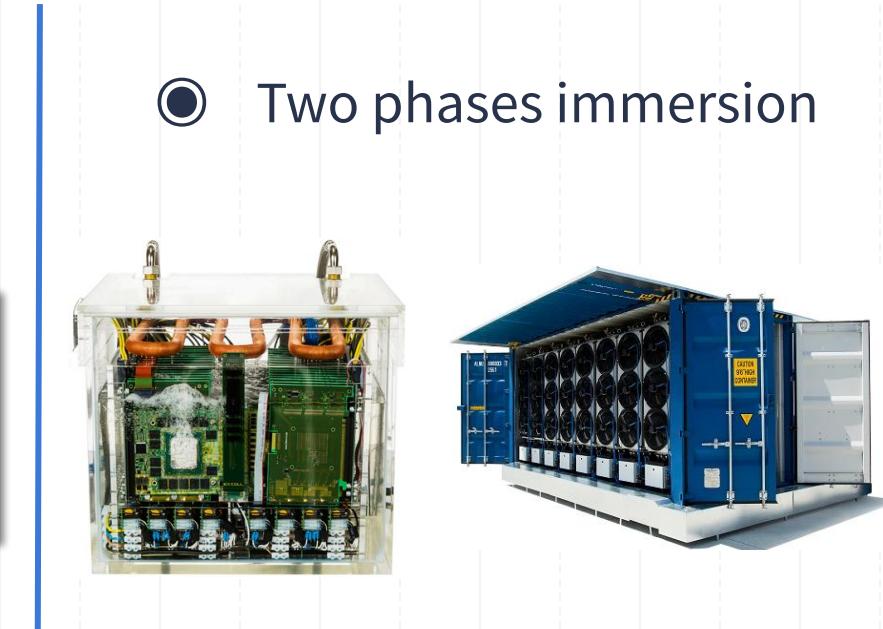


# IMMERSION COOLING METHODS

## One phase immersion



## Two phases immersion



# ENERGY CONSUMPTION OF DATA CENTERS

- Tianhe-2 (Top 1) > 200.000 MWh / year
- 2020: Top 1 Data Center  $\approx$  1 nuclear plant
- Worldwide:

500 000 Data Centers

**Energy: 200.000.000.000 € / year**