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Neural Network-based Predictive Control (NN-MPC) System for Energy Optimization in Sports Facilities: A Case Study

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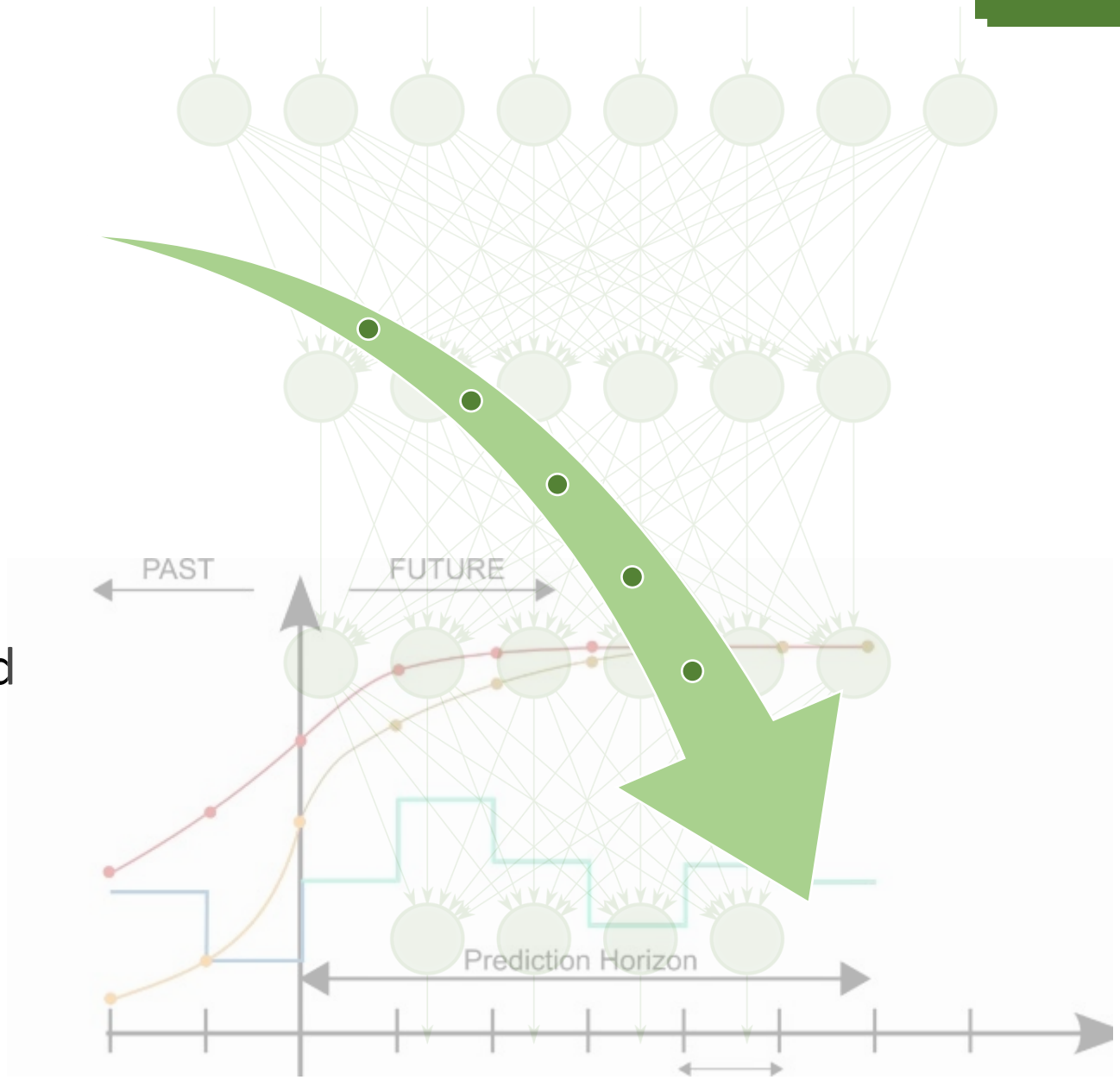

Introduction

- The buildings sector accounts for[1]:
  - Over one-third of global final energy consumption
  - Nearly 40% of total direct and indirect CO2 emissions
- Energy demand from buildings continues to rise, driven by:
  - Improved access to energy in developing countries
  - Greater ownership and use of energy-consuming devices
  - Rapid growth in global buildings floor area

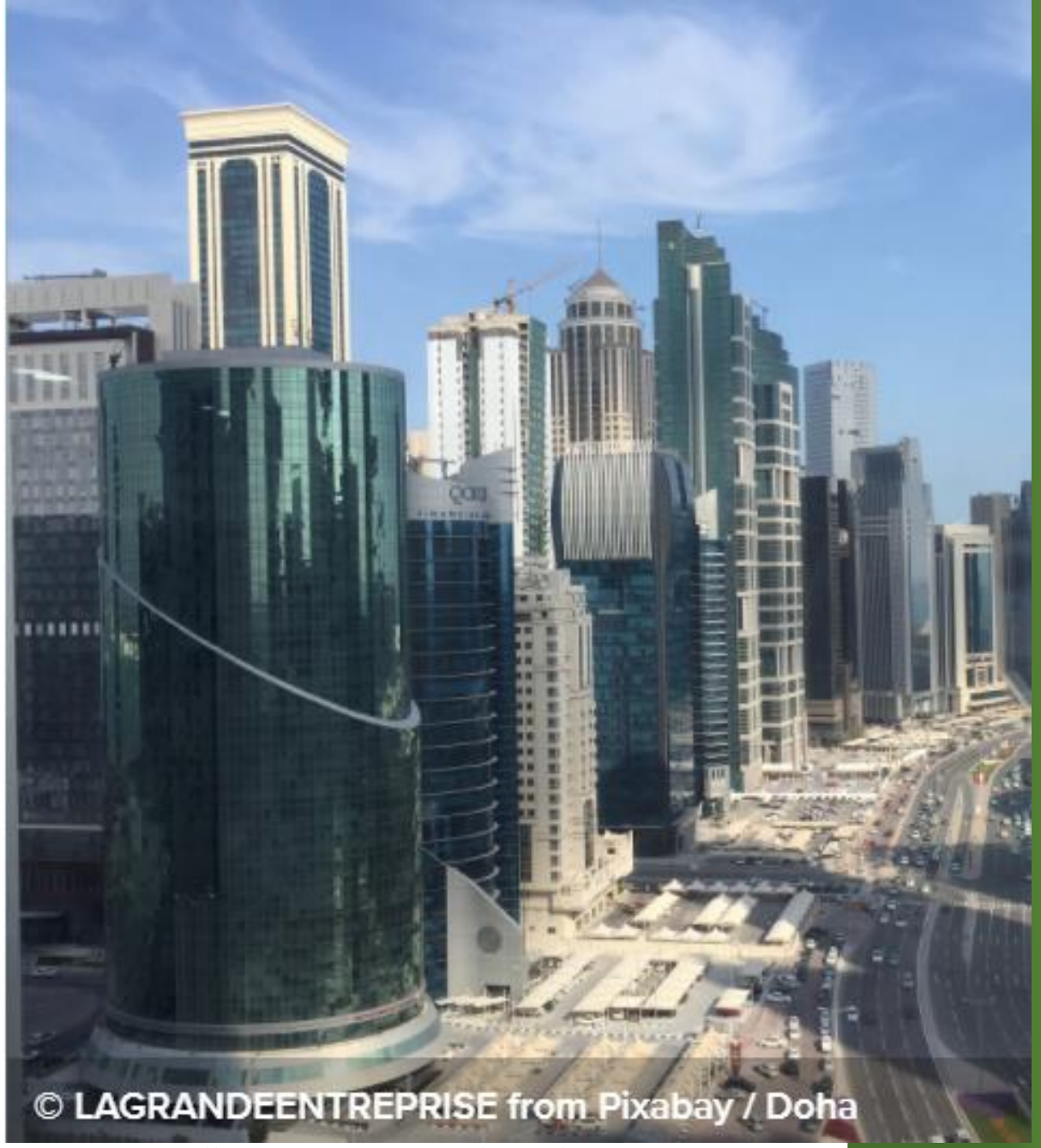

Image source: https://www.skyscrapercenter.com/country/qatar. Accessed on 7th of October 2021.

[1] https://www.iea.org/topics/buildings. Accessed on 10th of March 2021.

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Introduction

- The great dependence on fossil fuels is a key factor
- Mitigating the **climate change** is a key challenge of the 21st century [2]
- The world urgently needs to use energy efficiently while embracing clean energy sources

Image source: https://rmi.org/financing-the-transition-from-coal-to-clean-energy/
Accessed on 7th of October 2021

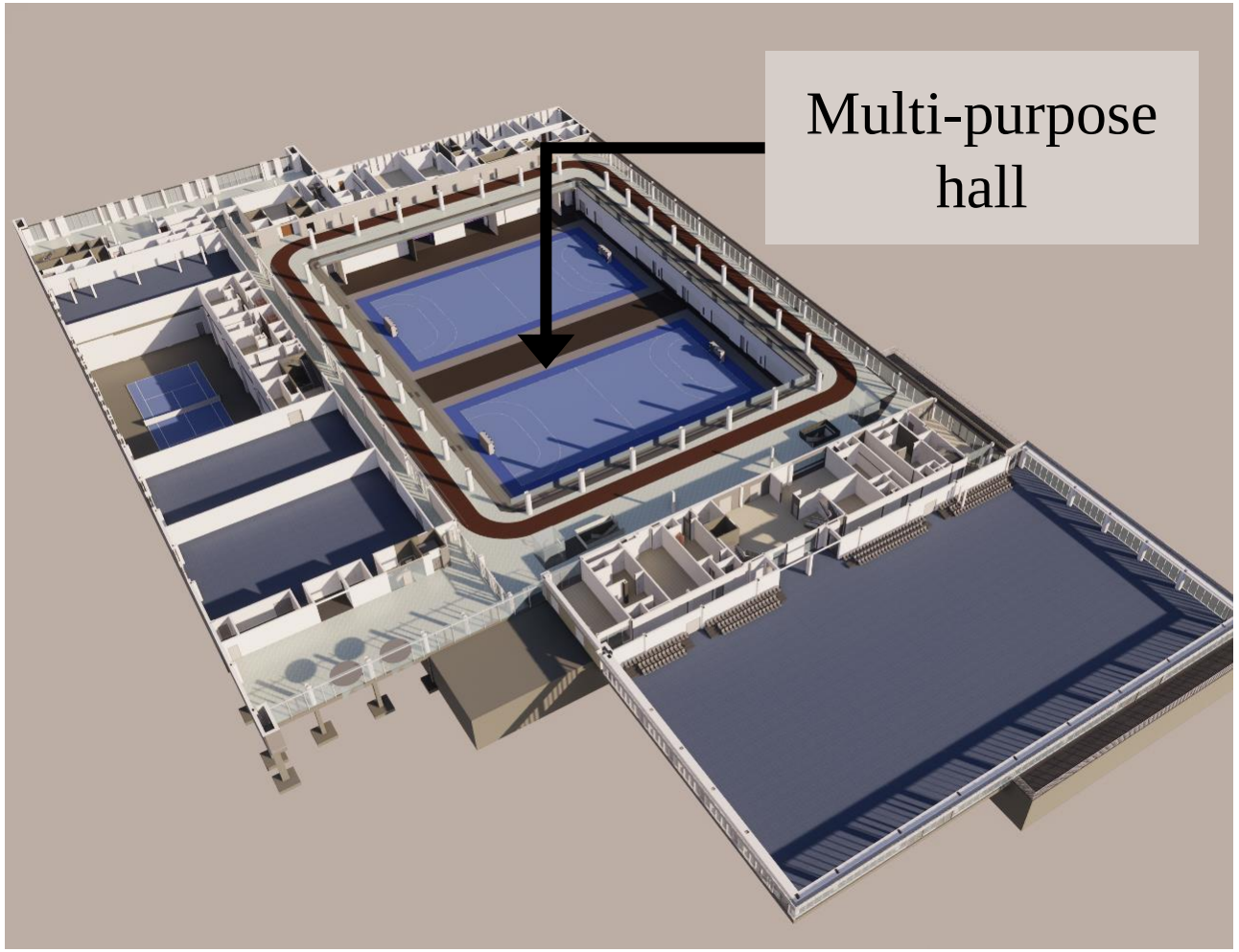
[2] www.eea.europa.eu. Accessed on 10th of March 2021.

Objective

- The theory of model predictive control (MPC) is combined with neural networks (NNs) for temperature setpoint selection to achieve energy and performance optimization of sports facilities
- The proposed approach represents a temperature setpoint optimization system that accounts for the current and future system transitions in the decision-making process

Description of the Case Study

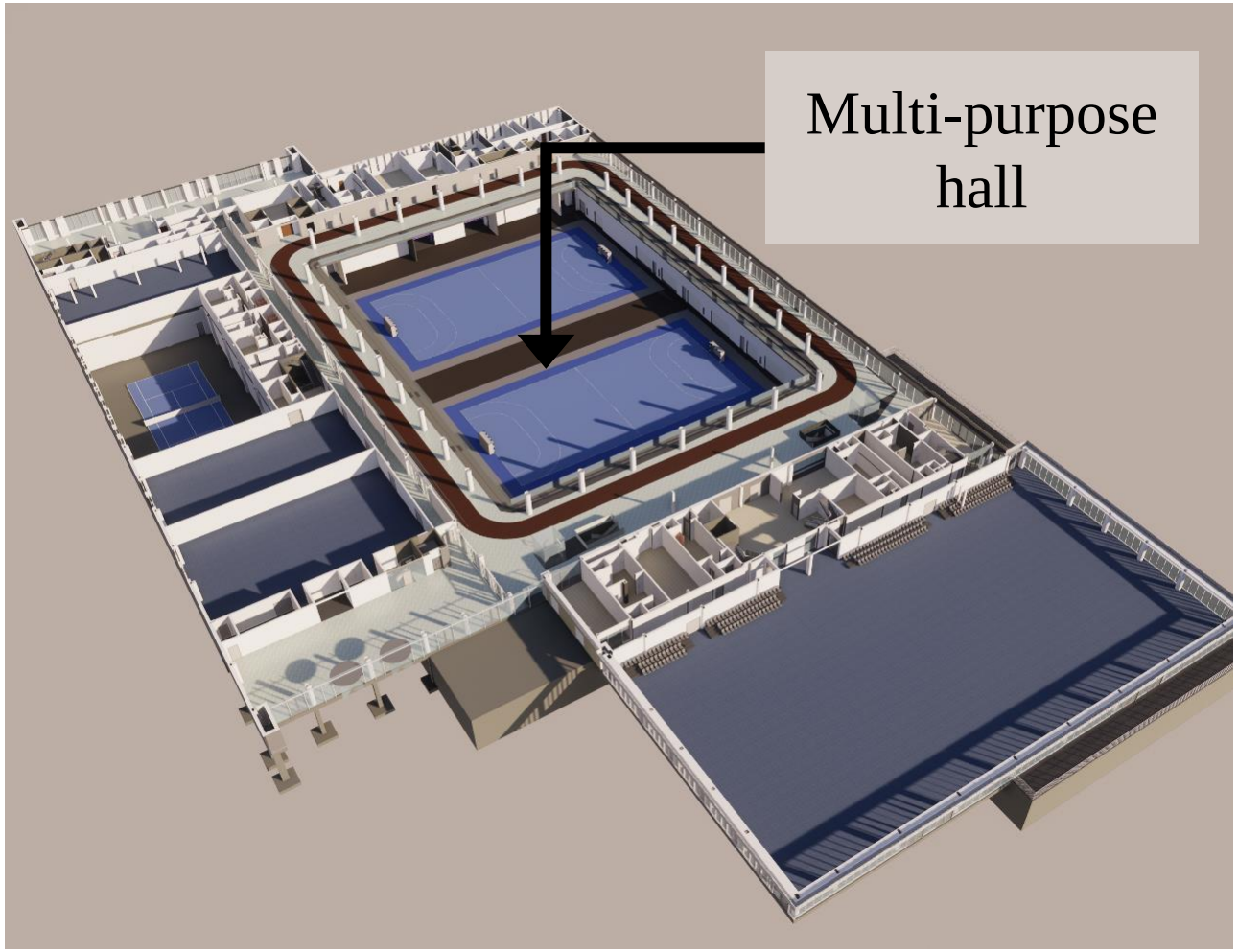
- The sports and events complex of Qatar University operates from 8 am to 3 pm
- The case study in this work is demonstrated on the multi-purpose hall, the largest conditioned space in the complex
- The hall extends from the ground floor to the roof with a total floor area of about 7,500 m^2



The image is a courtesy of the Capital Project Department of Qatar University.

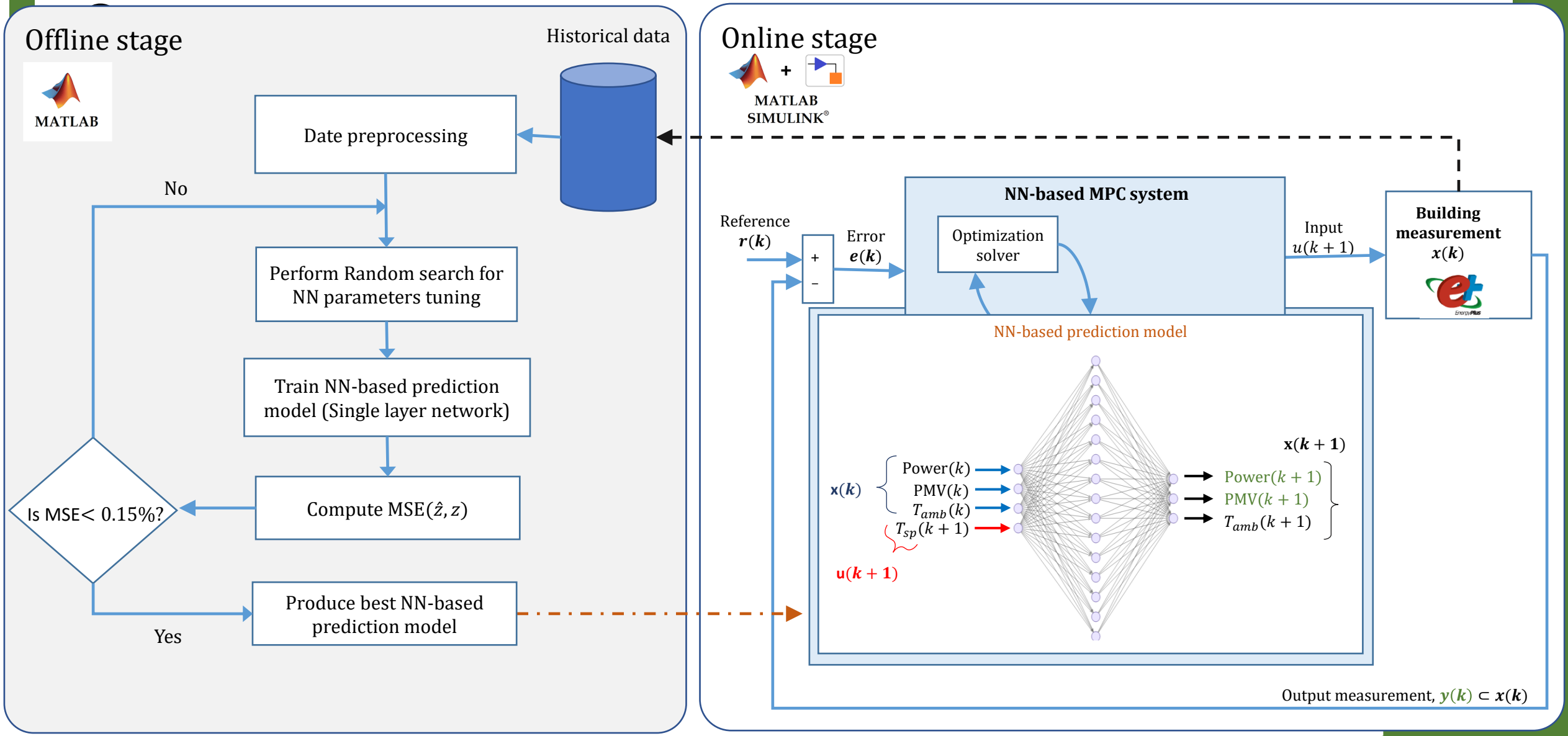
Description of the Case Study

- It is controlled at a temperature of 22°C during occupancy period
- The sports mode of the multi-purpose hall accommodates about 1200 people
- The building information model of the complex was used to develop the Energy Plus simulation model using Design Builder software



The image is a courtesy of the Capital Project Department of Qatar University.

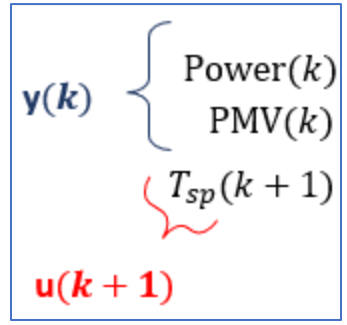
The Proposed NN-based MPC Approach



The Proposed NN-based MPC Approach

- **Theory of Model-Predictive Control (MPC):**
  - The MPC system consists of an **optimizer** and a **prediction model** of the building operation to decide the temperature setpoint given a cost function, J:

$$\mathrm{J} = \sum_{j=1}^{n_y} \sum_{i=1}^{n_p} \frac{w_j}{s_j} e_j^2(k+i|k) + \sum_{i=0}^{n_{p-1}} w_{\Delta u} \Delta u^2(k+i|k)$$

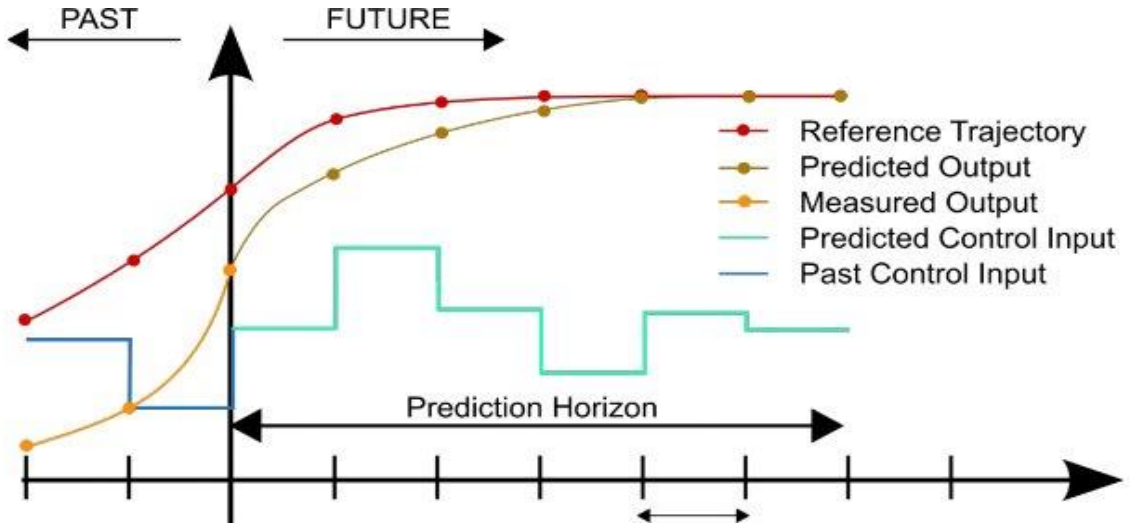


States at time k	**Outputs** at time k	**Reference** at time k	**Input** at time k	**Error** at time k
$x(k)$	$y(k)$	$r(k)$	$u(k)$	$e(k) = y(k) - r(k)$

  - The main parameters of the MPC are:
- prediction horizon, n_p determines the extent the controller investigates the future when optimizing $u(k)$
- control horizon, $n_c \in [1, n_p]$, represents the number of control actions $u(k)$ to be optimized at every step
- output weights, w determine the relative importance of the variables to the optimization objective
- Scale parameters, s to normalize the error signals to avoid optimization failure or sub-optimality due to output variables' diverse magnitudes

The Proposed NN-based MPC Approach

- **Theory of Model-Predictive Control (MPC):**



$$\mathbf{y}(k) \begin{cases} \text{Power}(k) \\ \text{PMV}(k) \end{cases}$$

$$T_{sp}(k+1)$$

$$\mathbf{u}(k+1)$$

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Image source: https://control.com/uploads/thumbnails/model-p-c-5.jpg. Accessed on 27th of September 2021

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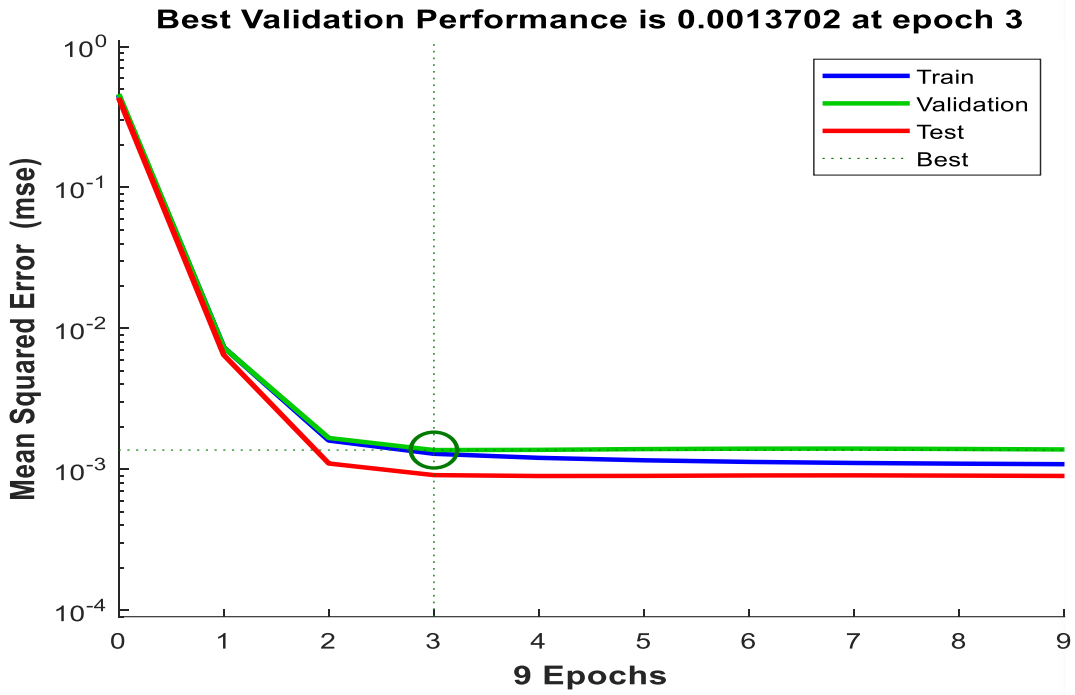
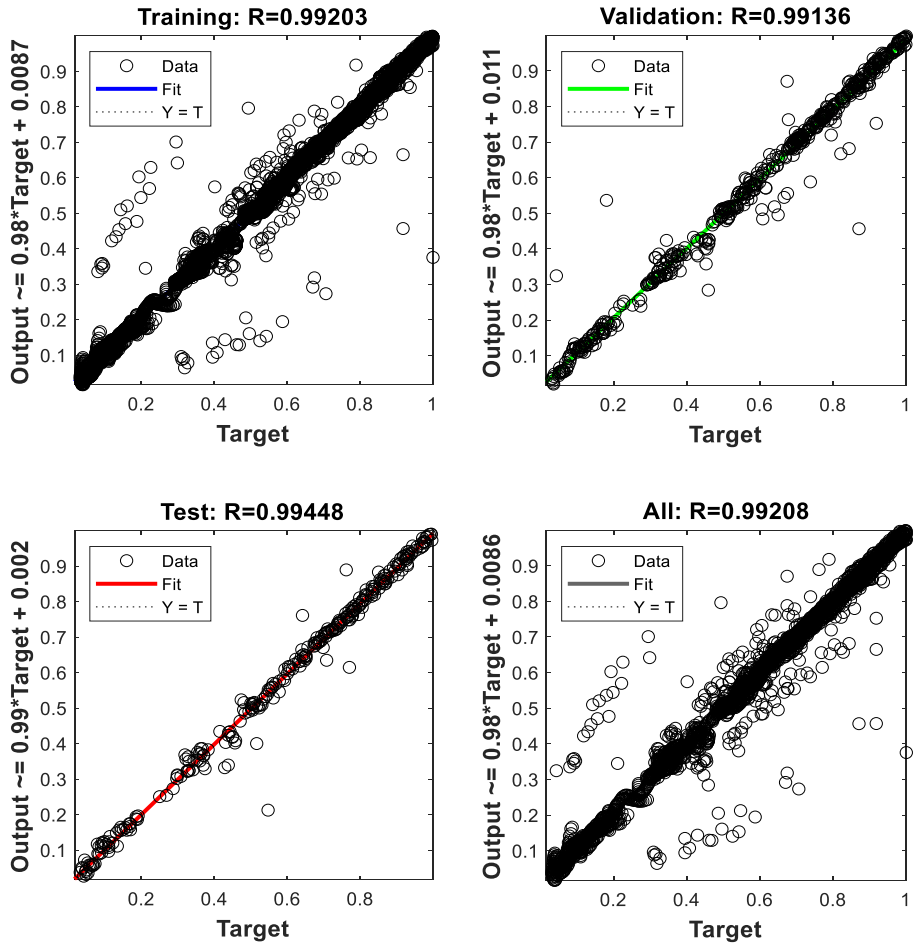
Results and Discussion

- Training of the NN-based prediction model:





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Results and Discussion

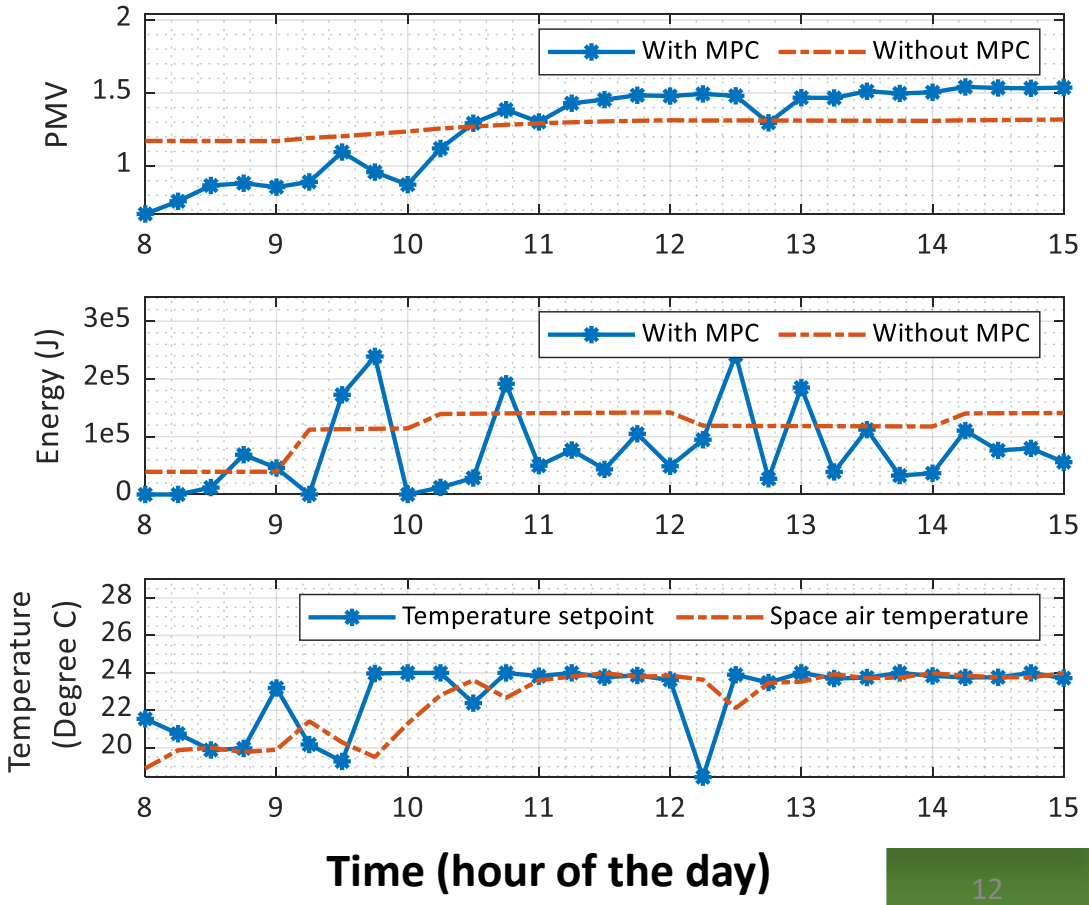
- The performance of the NN-based MPC system:

Energy reduction	Average PMV	n_p	n_c	w_1	w_2	Computation time per simulation step (sec)
33.45%	1.26	2	1	6.05	12.05	0.19
9.94%	1.20	3	2	6.05	0.05	0.22
19.08%	1.24	4	3	6.05	8.05	0.28

- n_p is the prediction horizon
- n_c is the control horizon
- w_1 is for PMV variable
- w_2 is for Energy variable

$$\mathbf{y}(k) \begin{cases} \text{Power}(k) \\ \text{PMV}(k) \end{cases} \quad T_{sp}(k+1) \quad \mathbf{u}(k+1)$$

- Comparison:



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Conclusion

- Effective utilization of a neural network-based MPC system for setpoint selection to achieve energy and performance optimization of sports facilities using simulation tools
- MPC systems allow integrated dynamic optimization that accounts for the future system behavior in the decision-making process
- A neural network was used for the system prediction element of the MPC system since it is unpractical and difficult to obtain explicit models for complex buildings such as sports facilities
- Neural networks are advantageous for their ability to represent complex interdependencies with high accuracy

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Conclusion

- The proposed approach was able to achieve a total energy savings of about 34%
- Considerations about the prediction model performance, tuning of the MPC settings, and optimization sub-optimality or failure are essential during both design and implementation phases
- The MPC system for setpoint optimization complements the existing management and automation system of the facility, thus can be easily integrated

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Future Work

❖ We plan to work on improvements of the proposed system by:

- Including additional controlling variables such as occupancy rate, air ventilation rate, etc.
- Expanding the objective to include factors related to the safety and health of users

❖ We plan to validate the proposed framework using practical experiments

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This research/publication was made possible by a National Priority Research Program NPRP award [NPRP12S-0222-190128] from the Qatar National Research Fund (a member of The Qatar Foundation).

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Thank you for your kind attention

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More information about the **SportE.3Q project** can be found in https://www.sporte3q.com/

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