CLEEN
Cluster for Energy and Environment

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Efficient Energy Use

How to predict energy flows?

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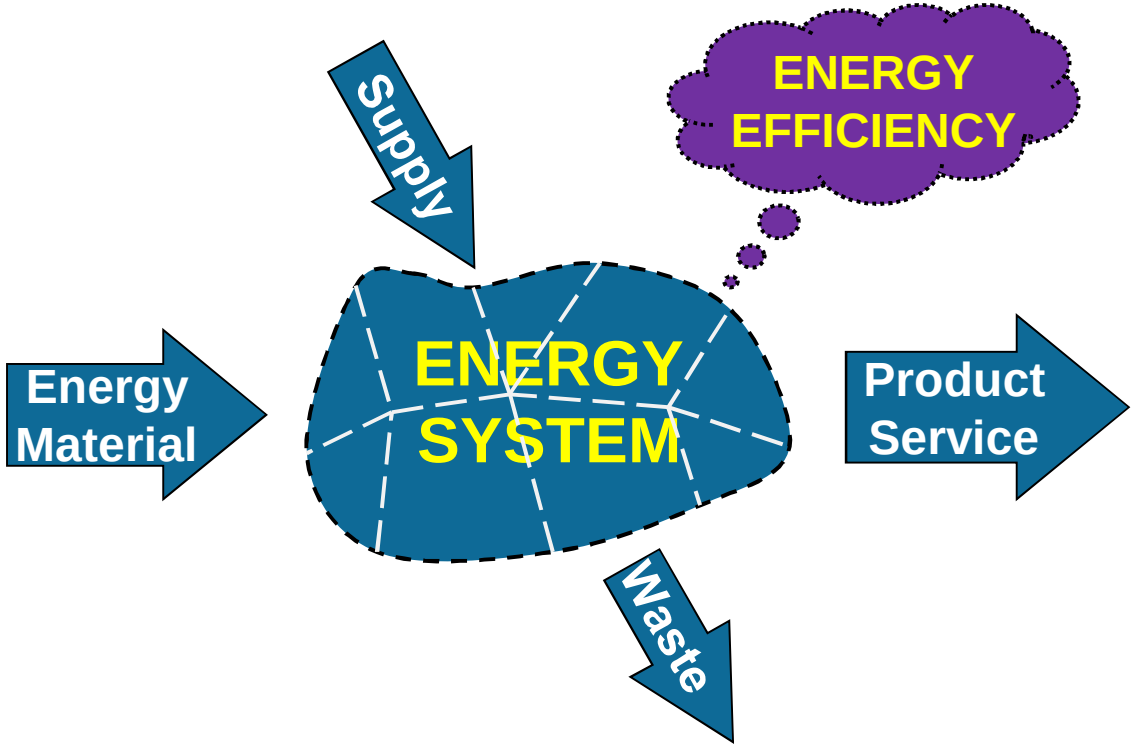
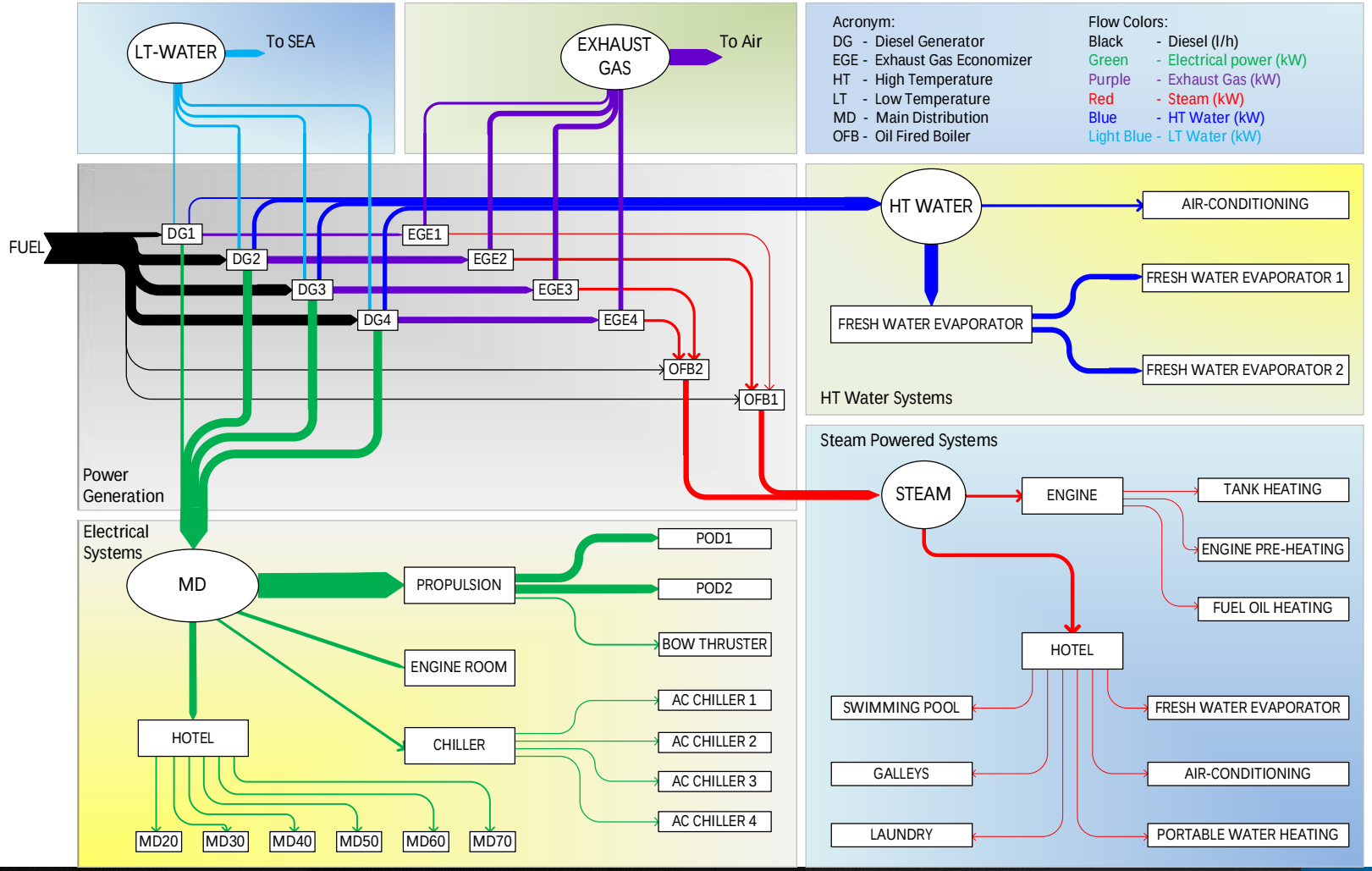
What is energy flow?

" **Energy flow** here refers to the **flow** of **energy** in different forms through a series of **interconnected processes** of an **energy system**."



What is energy flow?

- Example – How energy flows through a **cruise ship**



Why energy flow prediction?

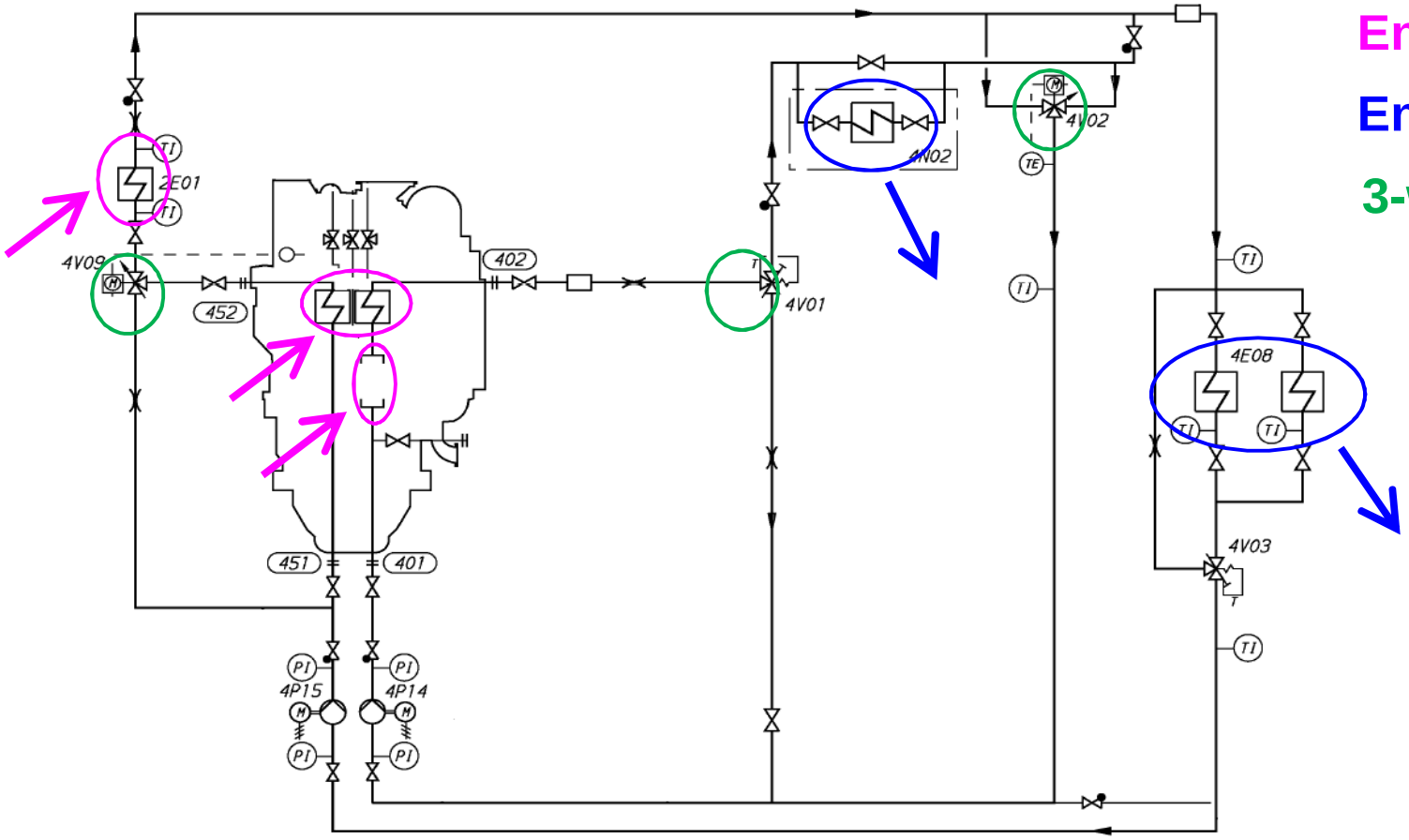
"Good operators should accommodate to **uncertainties**, and adjust their operations according to **what is likely to happen in the near future (prediction)**."

For **energy efficiency**, and for **safety.**

How to predict energy flows?

White box	Grey box	Black box
Deterministic approach	"**Combined**" approach	**Statistic** approach
• **Detailed physical modeling** of complex systems • Model structure is **known** and **deterministic** • Some environmental conditions **unknown**	• Some **prior knowledge** + some **data** • **Combined** data information with physical knowledge • At some level or in some parts deterministic • System **partly unknown** • Some environmental conditions **unknown**	• **Data-driven input-output models** • The models and their parameters have **little physical significance** • System **unknown** • Some environmental conditions **unknown**

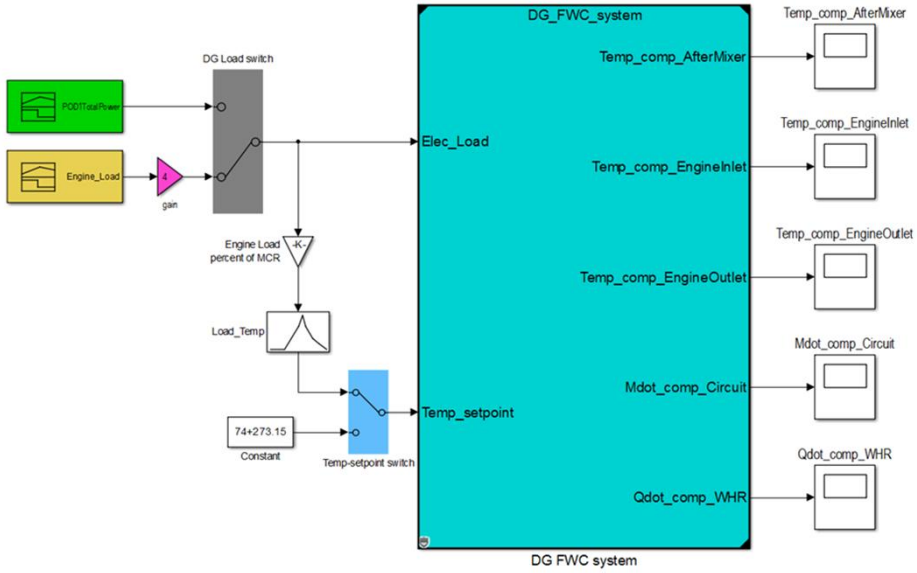
Ex.– Ship engine water cooling system



- Aim: To evaluate **advanced algorithms** for energy flow prediction with **waste heat recovery** in focus

Grey box approach

- Previously developed **ship energy flow simulator** used as a test bench for various prediction algorithms
  - **System-level approach** without knowing the system details
- Heat energy need **unknown**
- Environment **temperatures** (air and sea water) **unknown**
- To evaluate: **model structure, iteration, prediction horizon**



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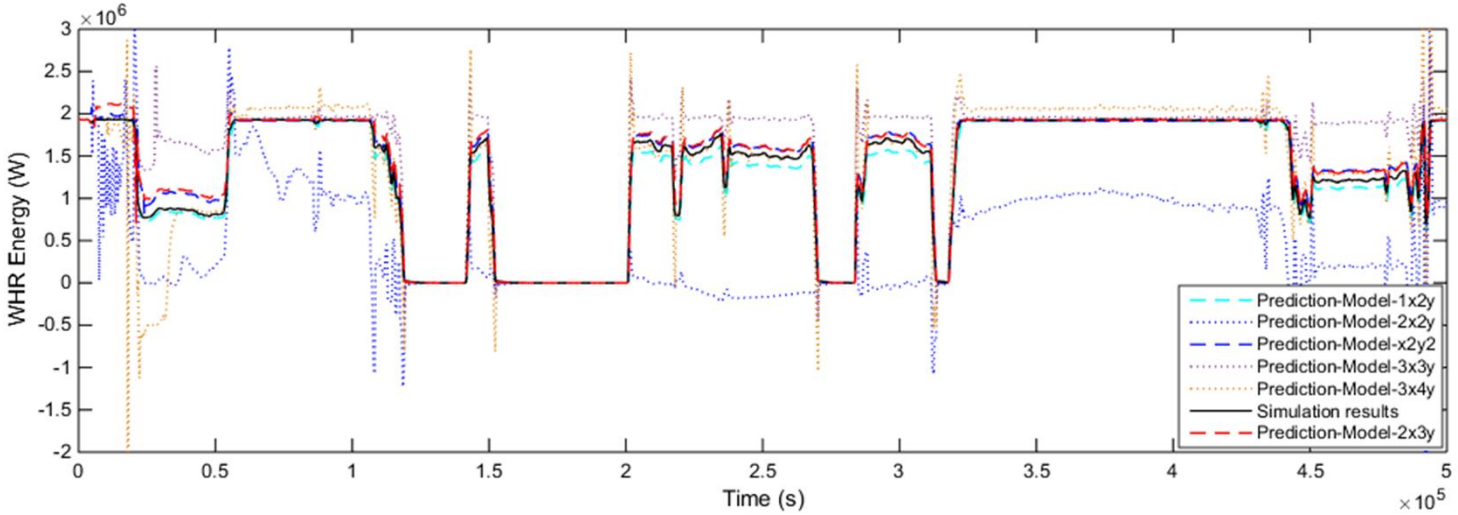
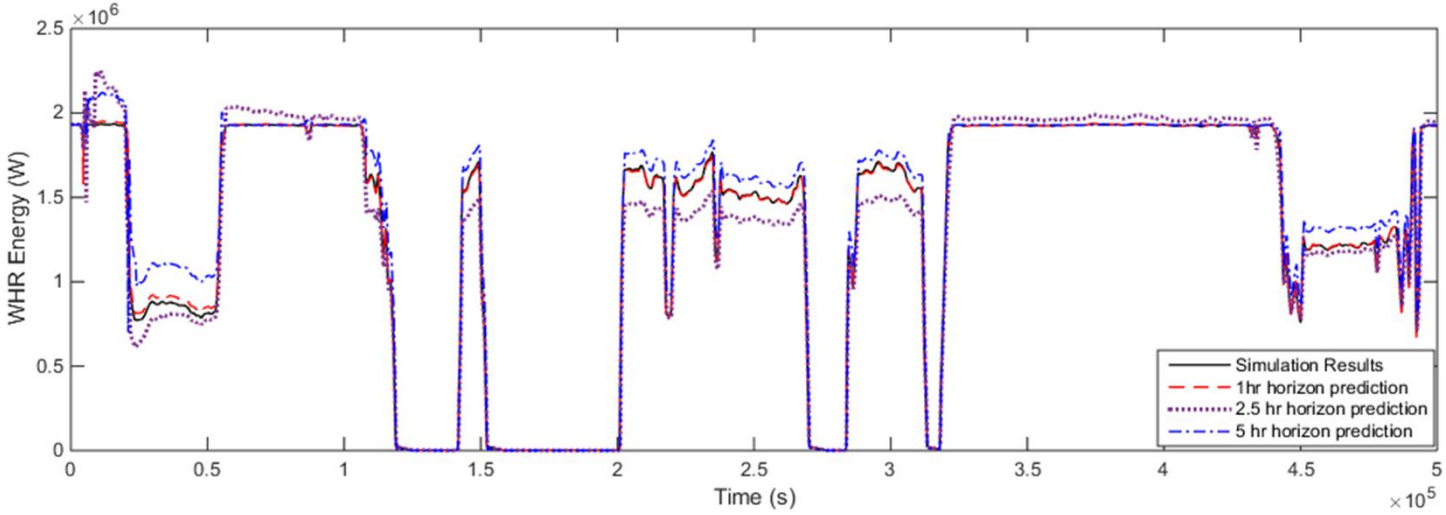
Grey box approach
(Regressive least squares (RLS) method)

a) Different model structures

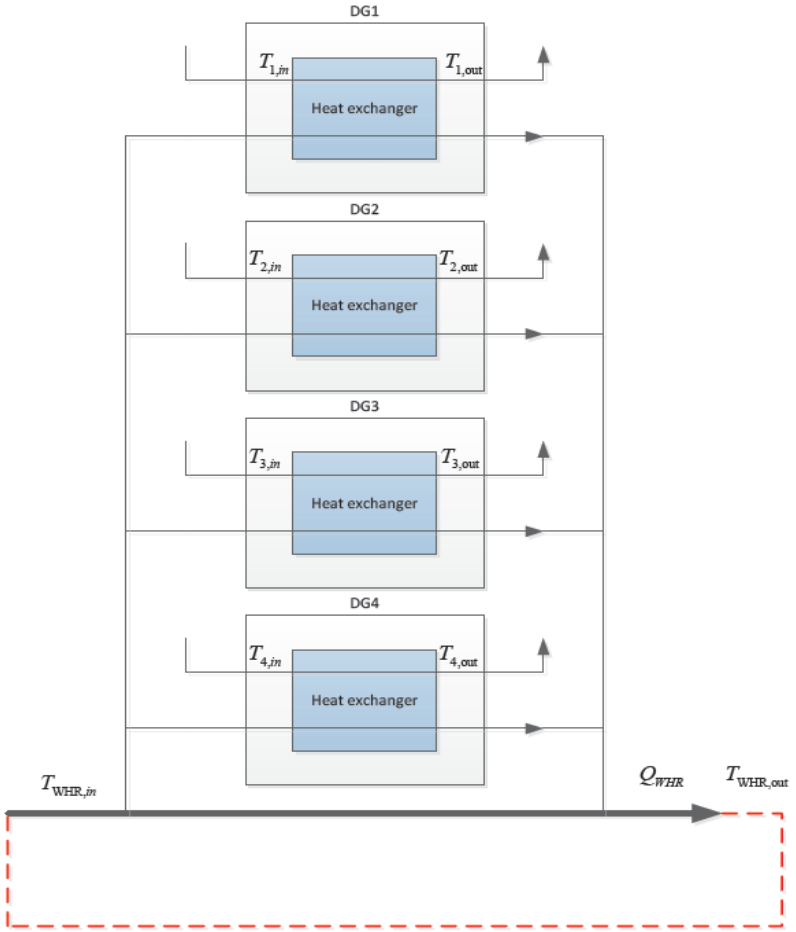


b) Different prediction horizons



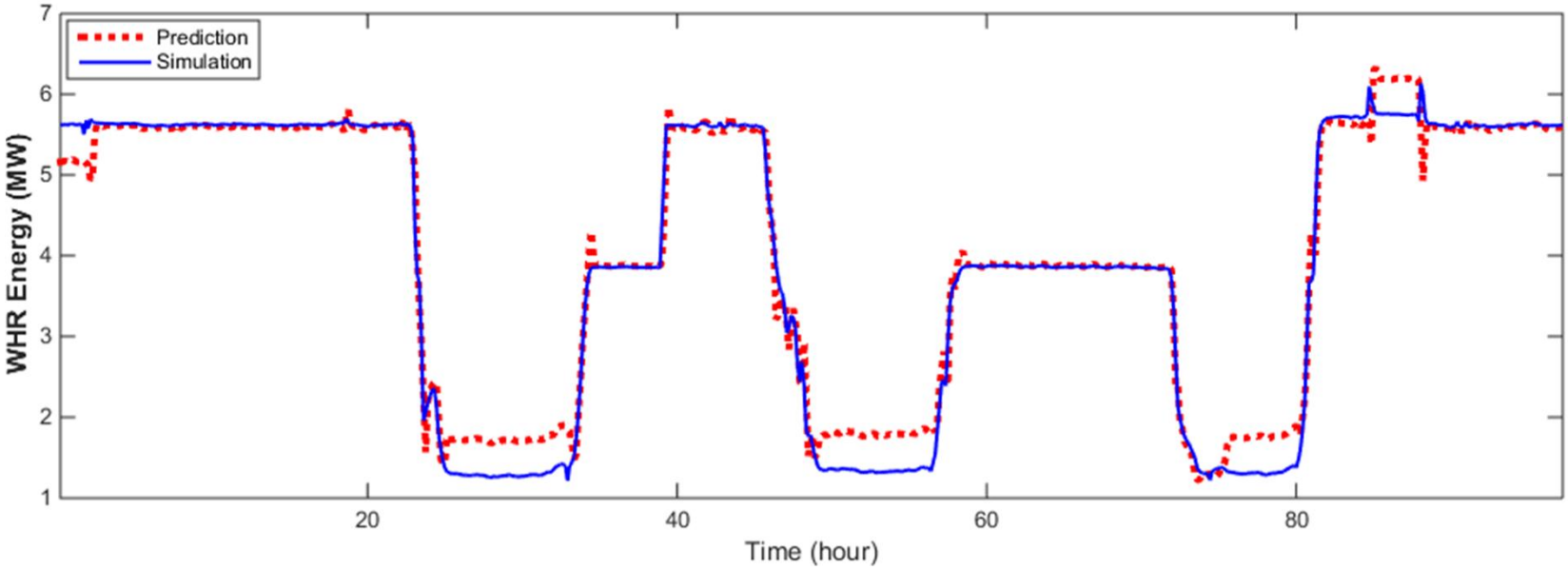
Black box approach

- The ship energy cooling water system is considered as a **black box**
  - without knowing the information on the system
- A large set of **measurement data** available for use
- Heat energy need **unknown**
- Environment **temperatures** (air and sea water) **unknown**
- To evaluate: **data set, model structure, training algorithm**



Black box approach (Neural Network method)

- Expanded ship fresh water cooling system
- **Inputs**: engine load of the four DG sets
- **Output**: total WHR energy
- Method: **NARX (nonlinear autoregressive exogenous)** method with Levenberg-Marquardt algorithm



Conclusions

- **Energy flow prediction** can provide operators valuable insights into **system operations** with **future aspects** into consideration
- Both grey-box and black-box approaches can deliver good prediction results for **small-scale systems** within reasonable horizons
- The practical performances of energy flow prediction depend on some **key factors of specific approaches**

- The methods are **general in nature** and easily applicable to other energy systems: **building, plant, town, city**

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Future plans

- To extend the energy flow prediction approaches to **larger-scale** energy systems
- To identify possible **bottlenecks** and to evaluate the practical **feasibilities** of the developed prediction methods
- To combine **system level optimization** with energy flow prediction methods so as to improve **energy efficiency** and to reduce **operational cost**
- To work together with partners to identify **business potentials** of the developed methods
- **Publication** of the research results
- **International collaboration** with top European universities