ATES System: A Practical Predictive Dynamics Model

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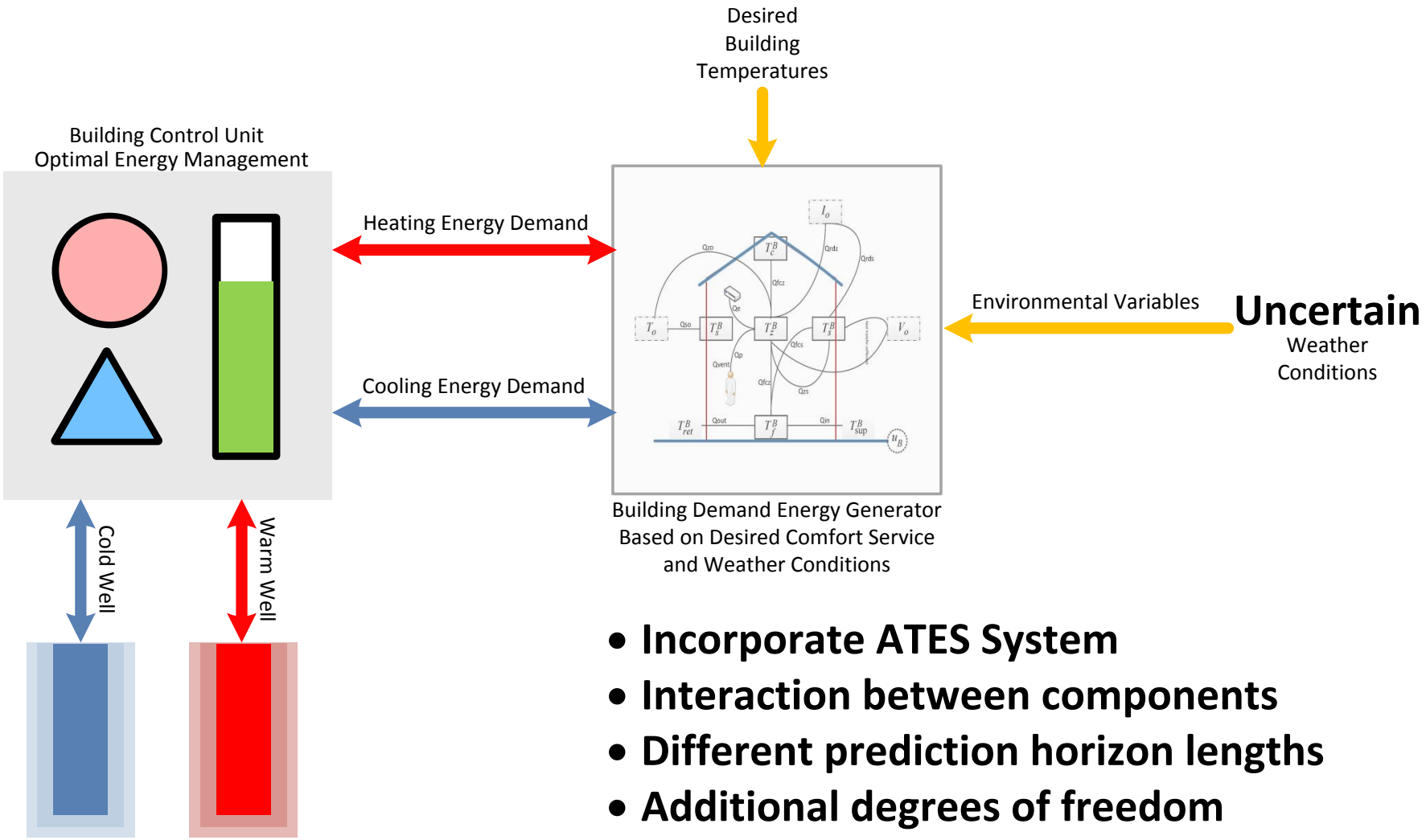
Delft University of Technology
Delft Center of Systems and Control

Users' Group Meeting

June 6, 2017

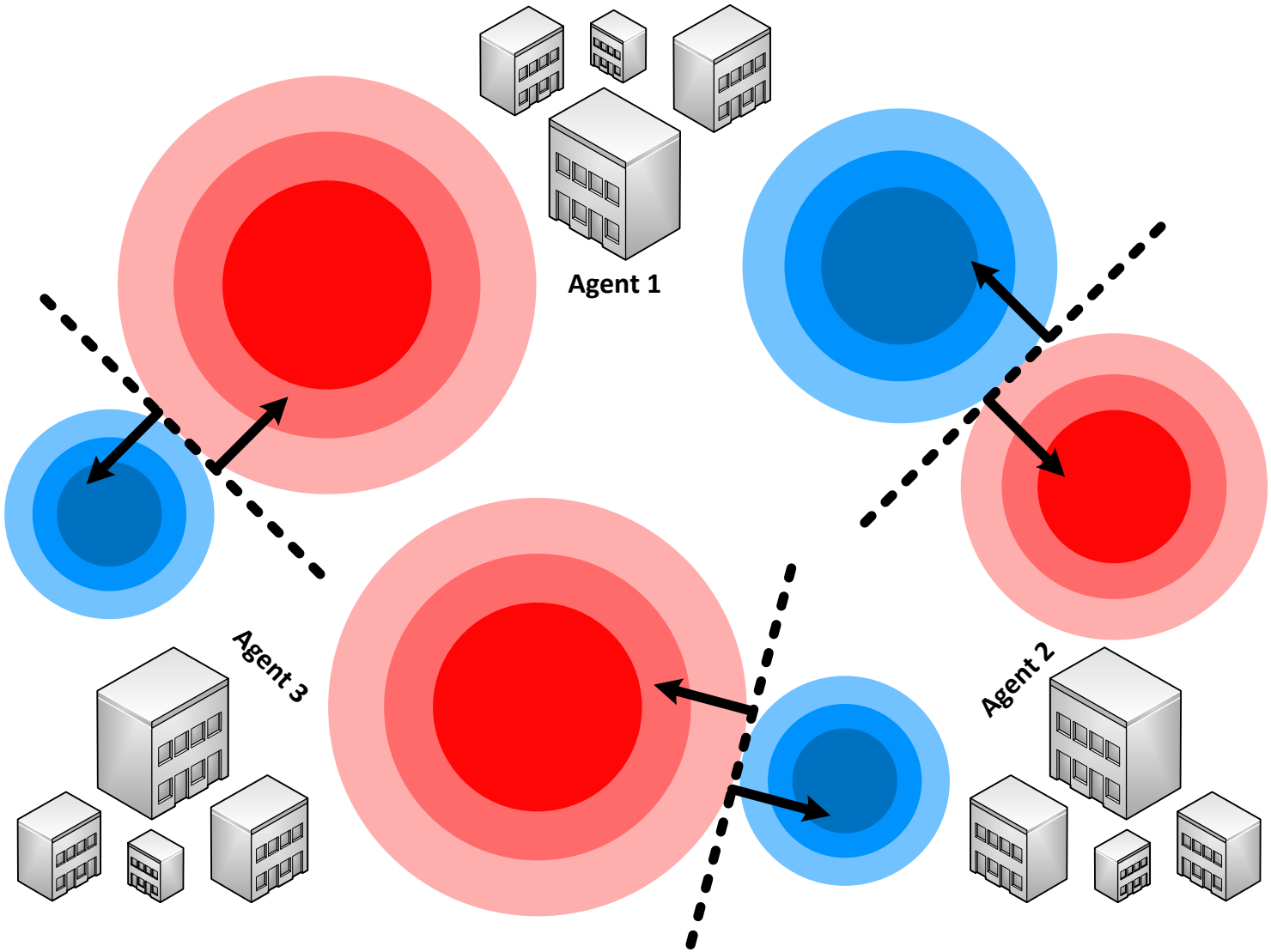
Recap: Building Climate Comfort and ATES Systems



- **Incorporate ATES System**
- **Interaction between components**
- **Different prediction horizon lengths**
- **Additional degrees of freedom**

[Rostampour, Keviczky, IFAC World Congress 2017]

ATES Systems in Smart Thermal Grids



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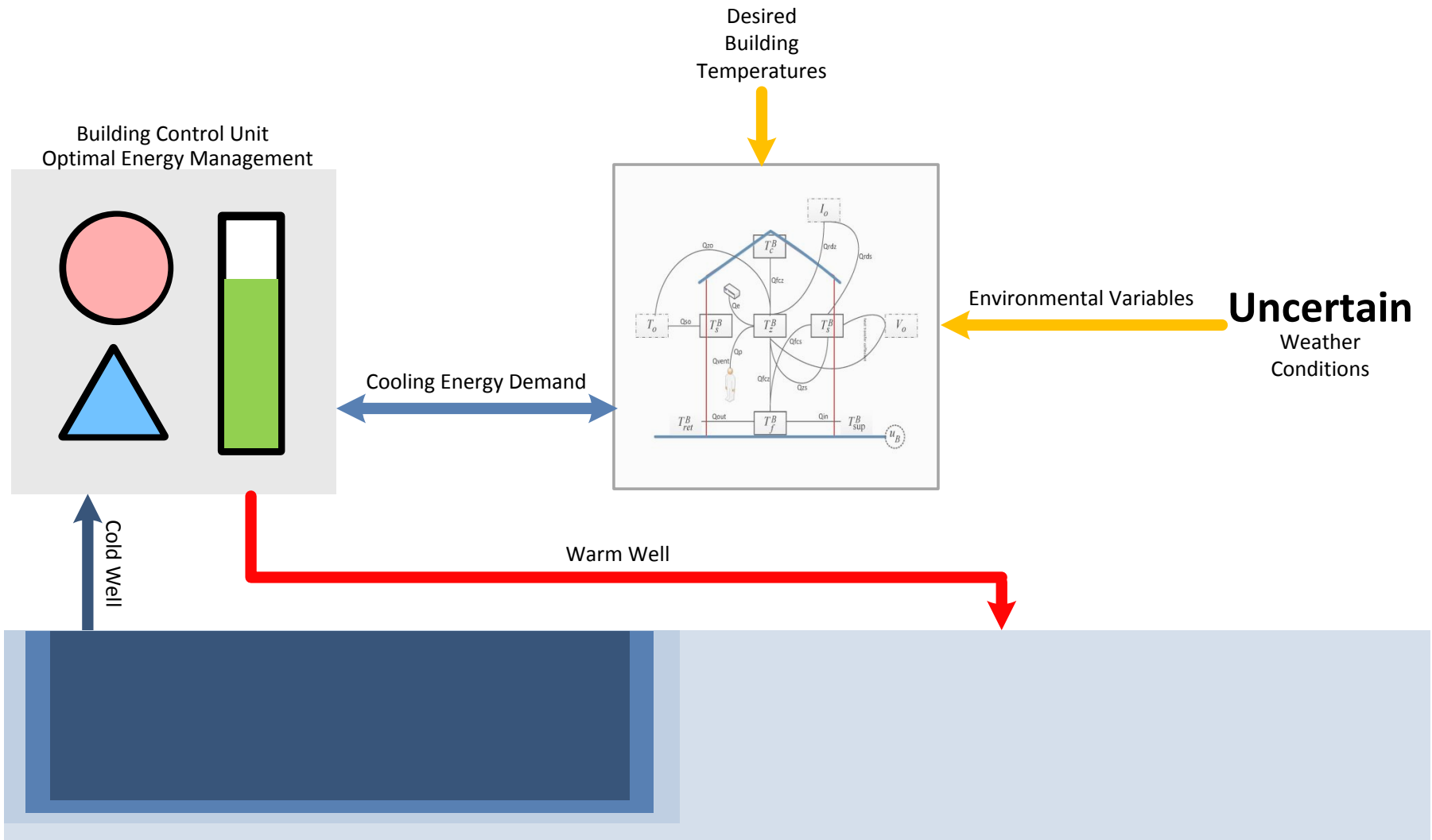
Outline

Model Predictive Dynamics: Cooling Mode



[Rostampour et al., European Geosciences Union 2017]

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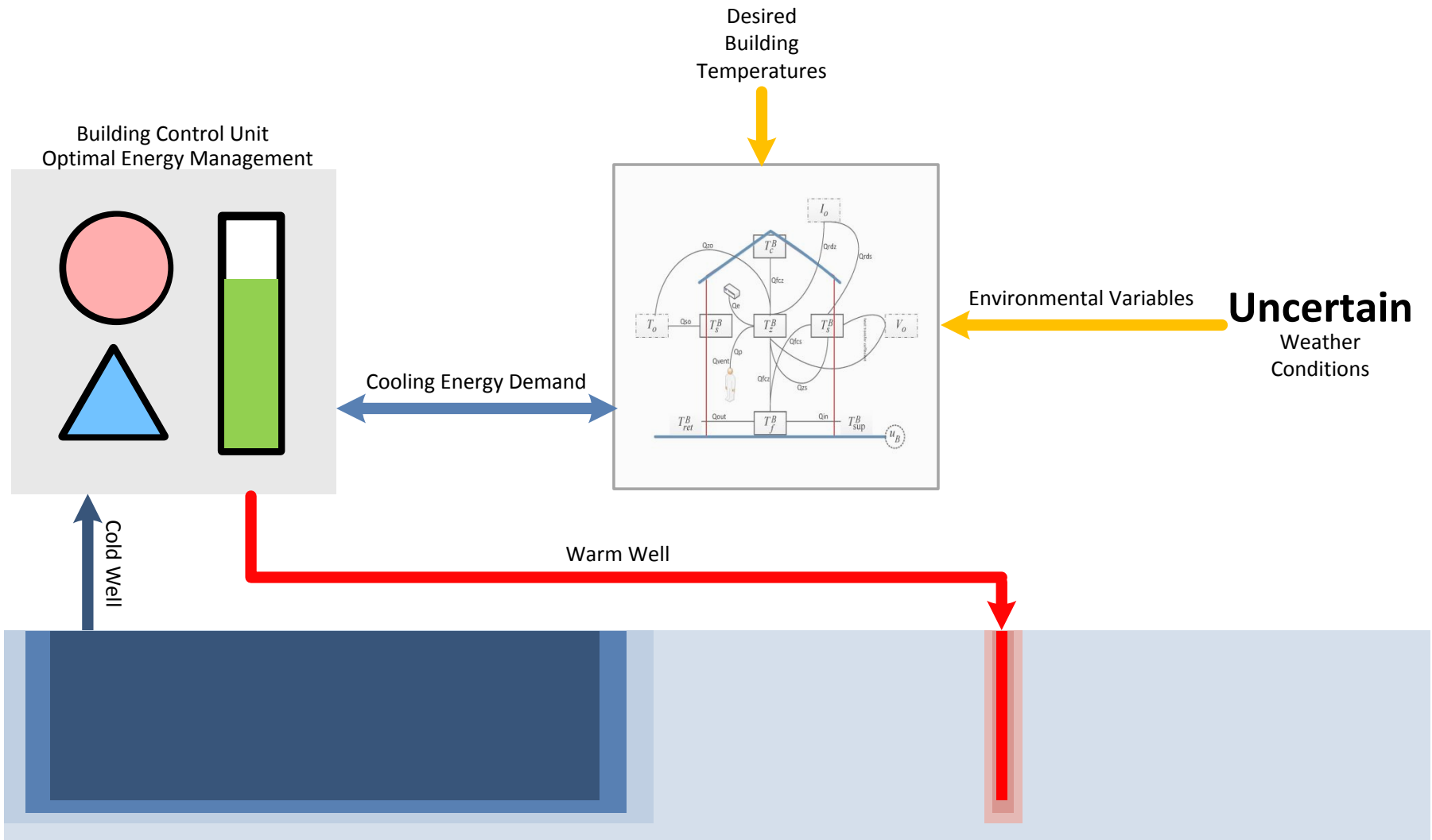

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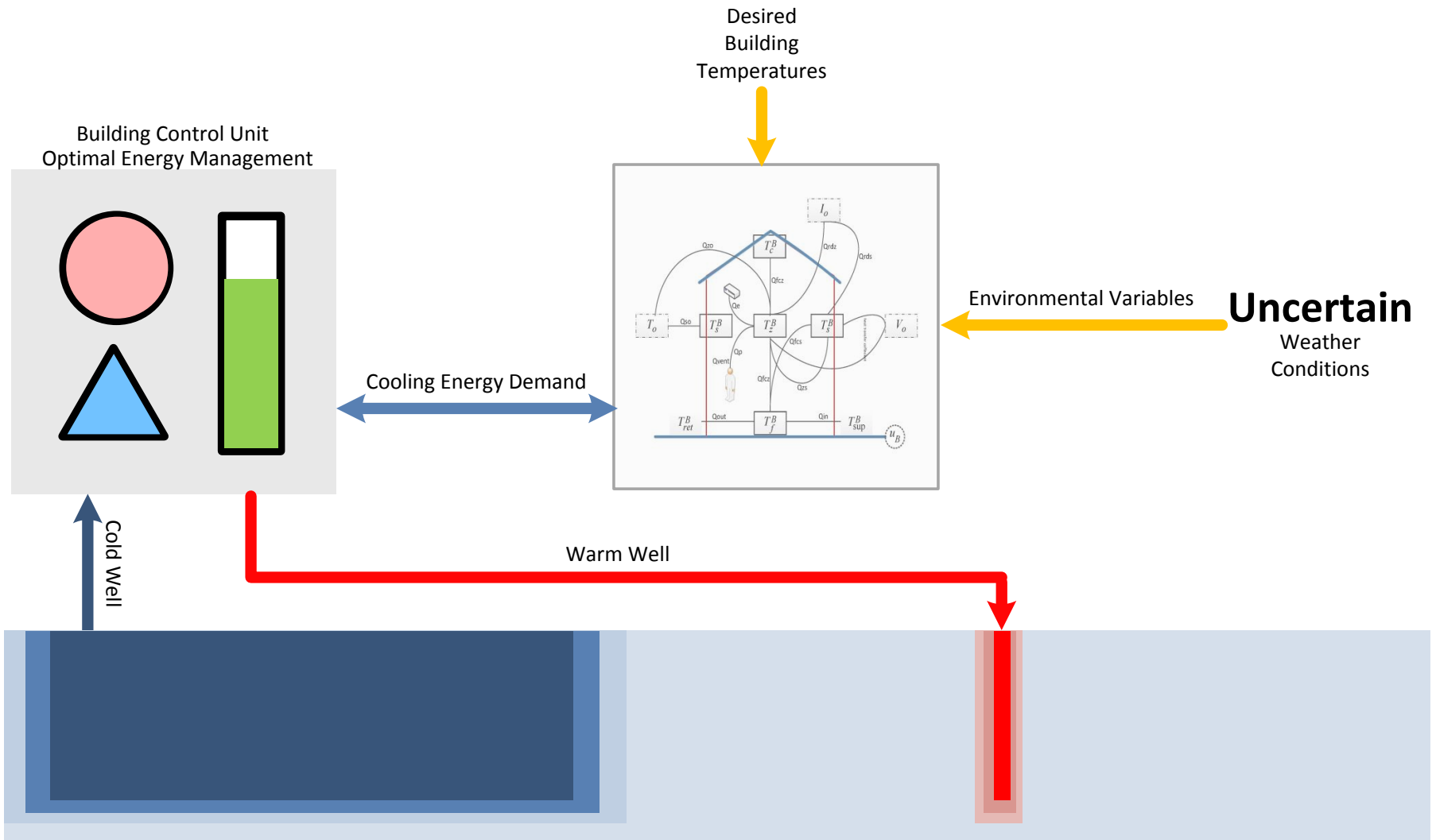

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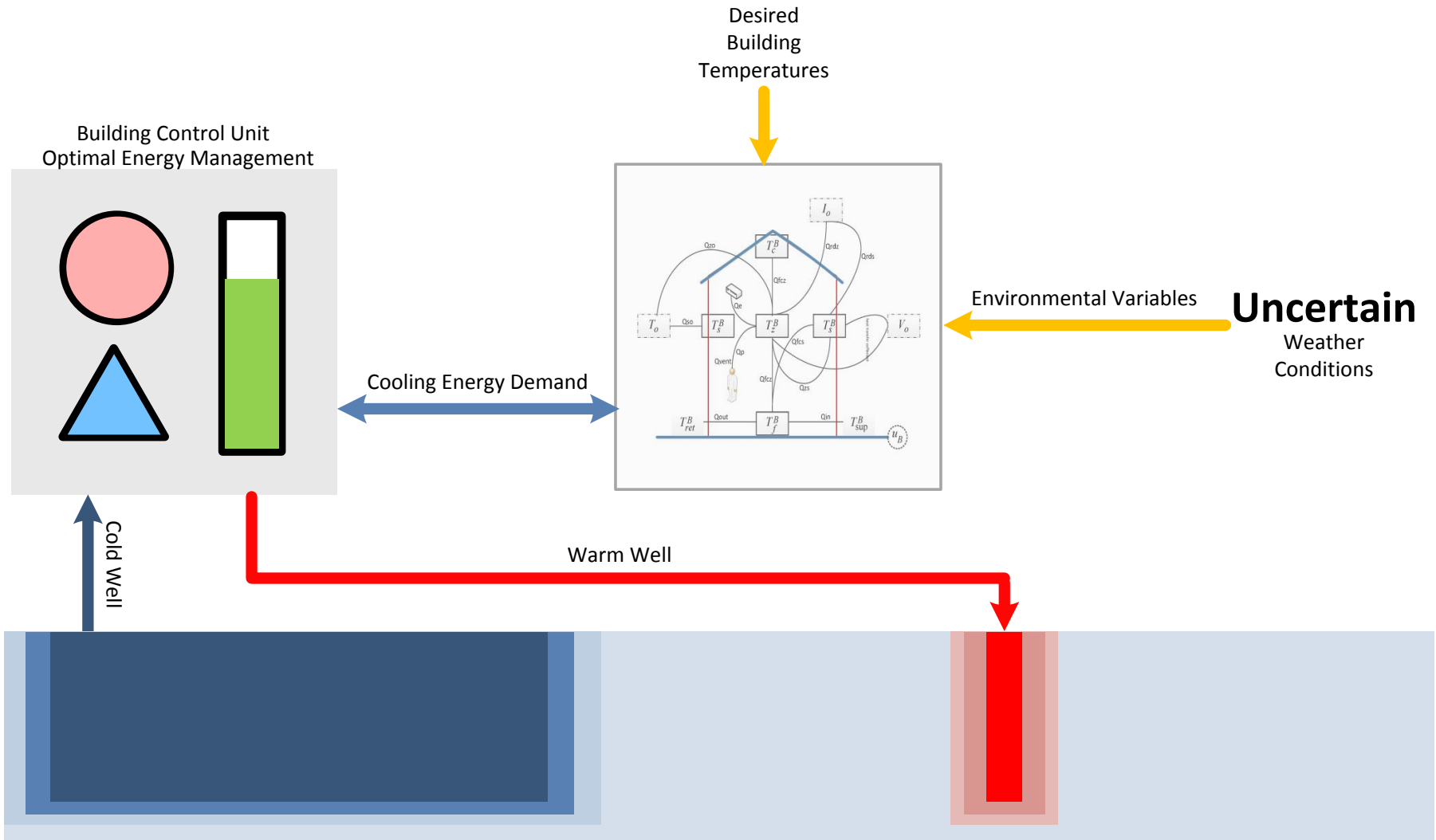

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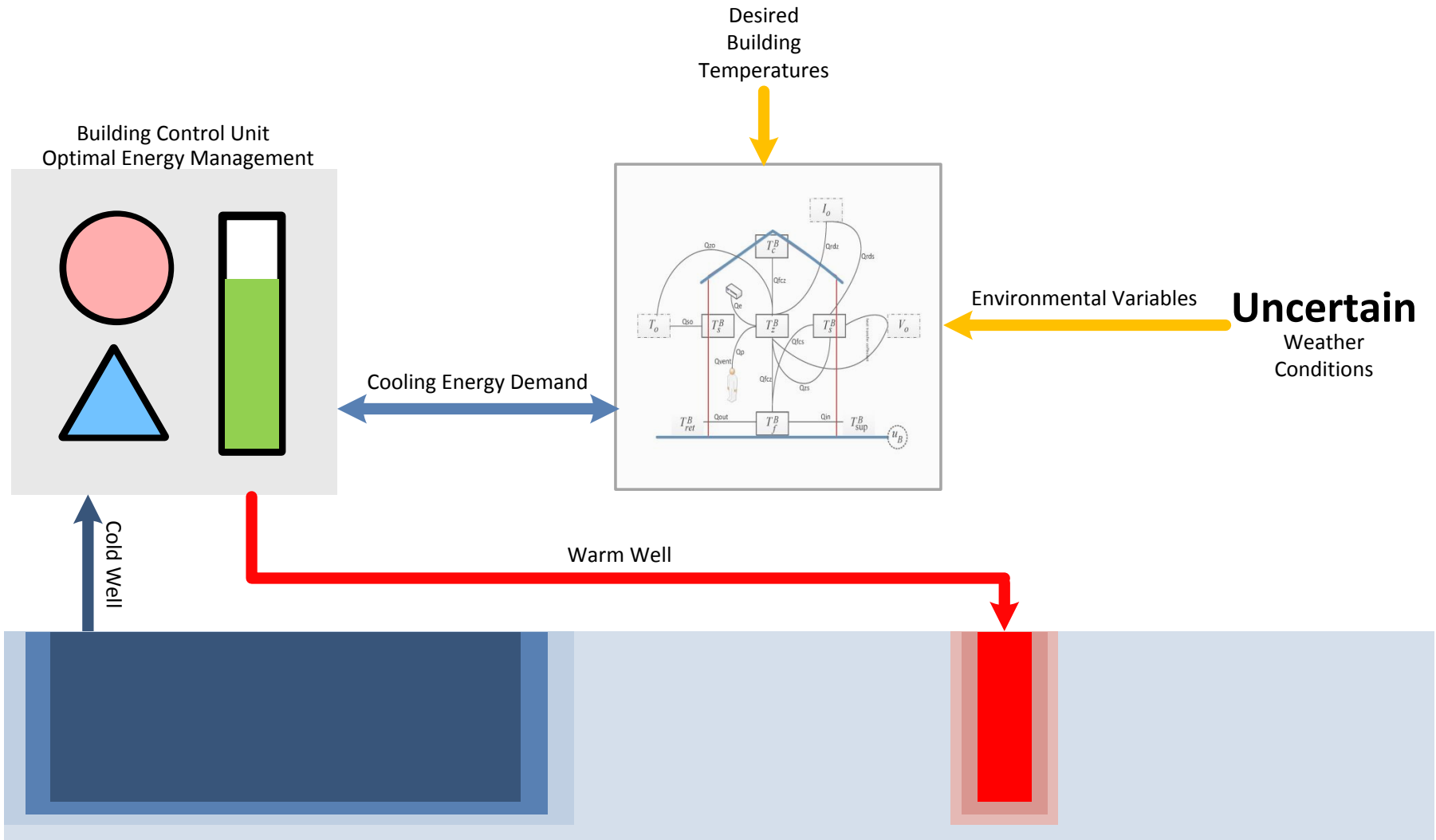

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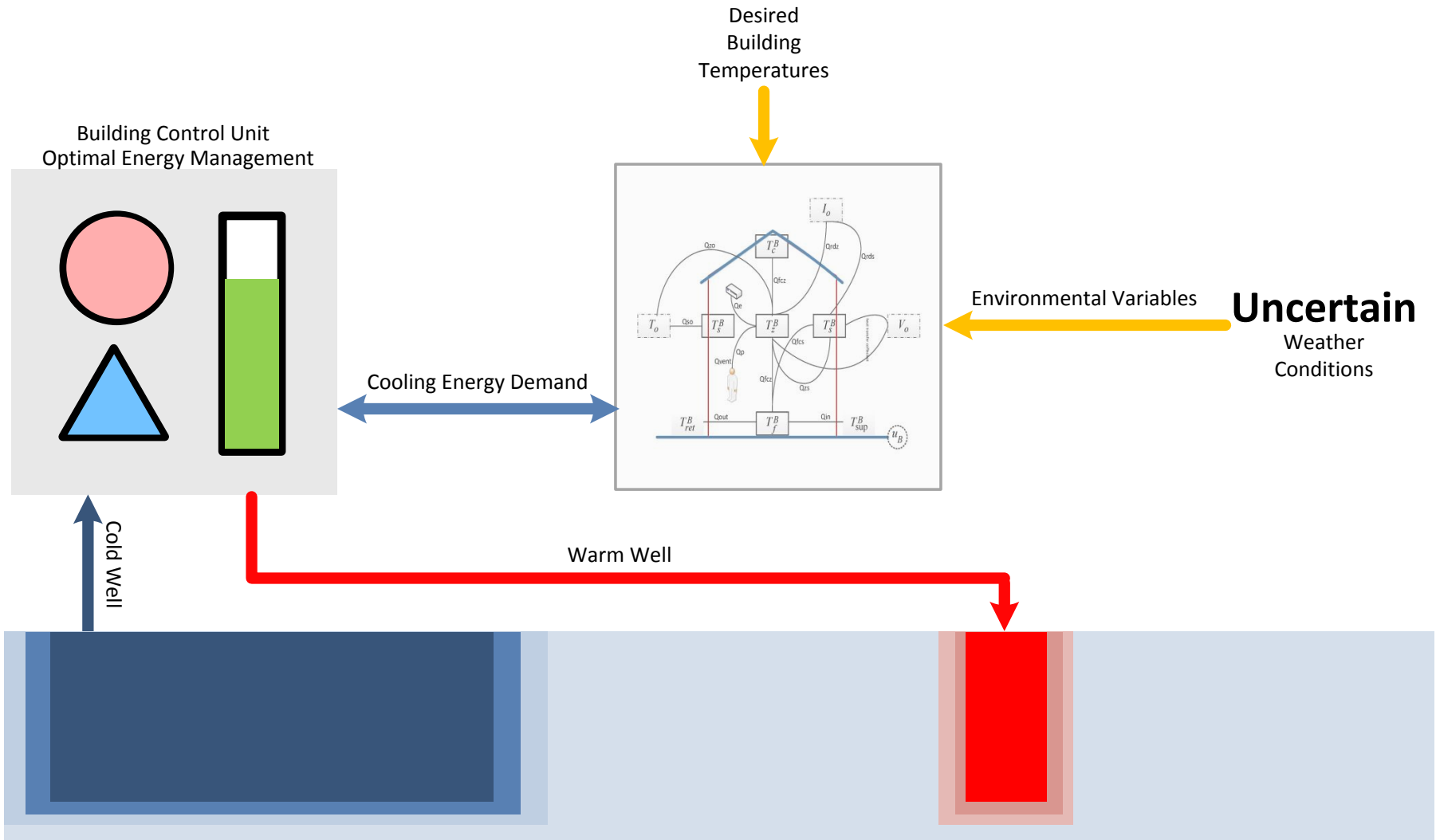

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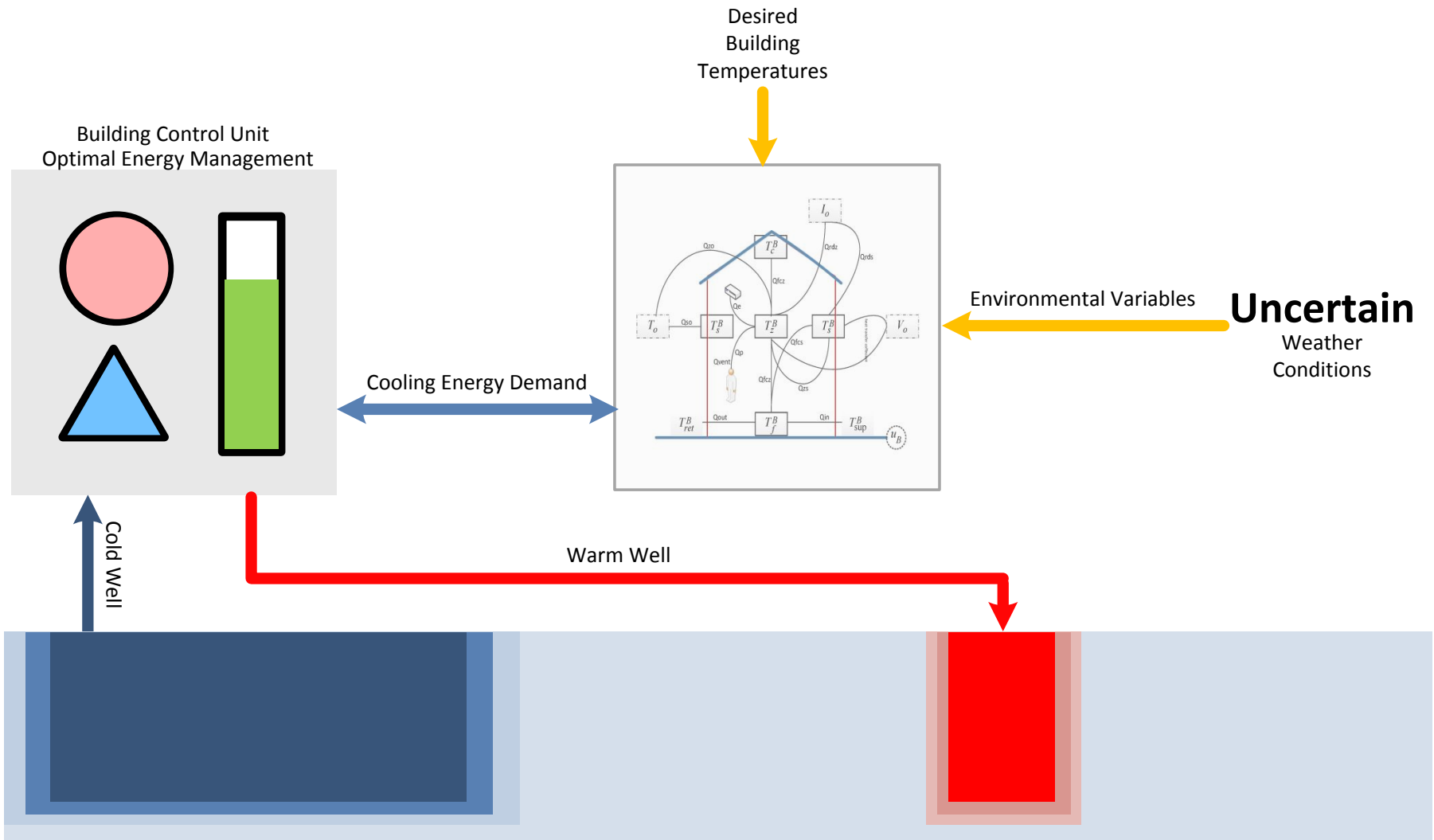

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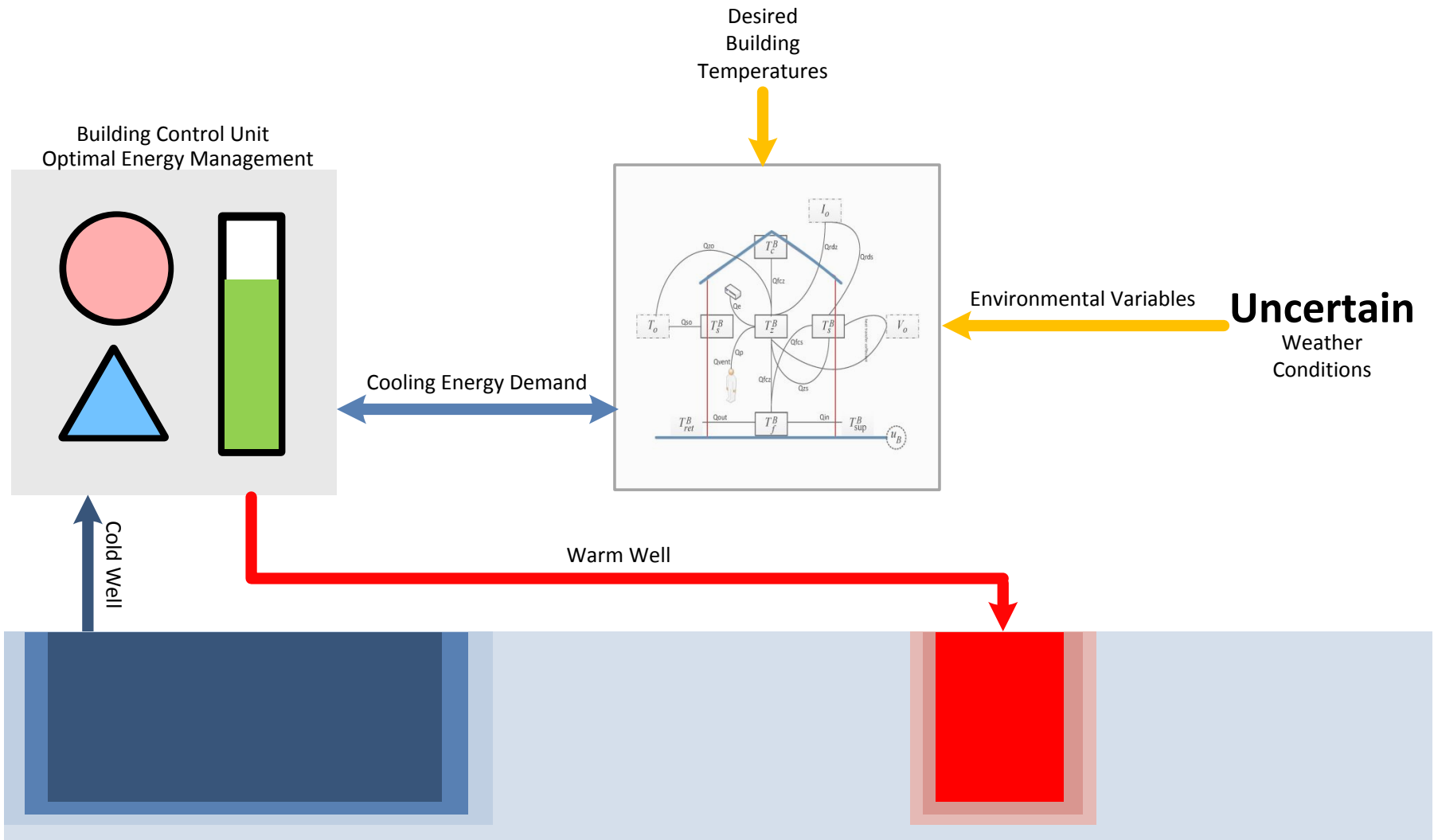

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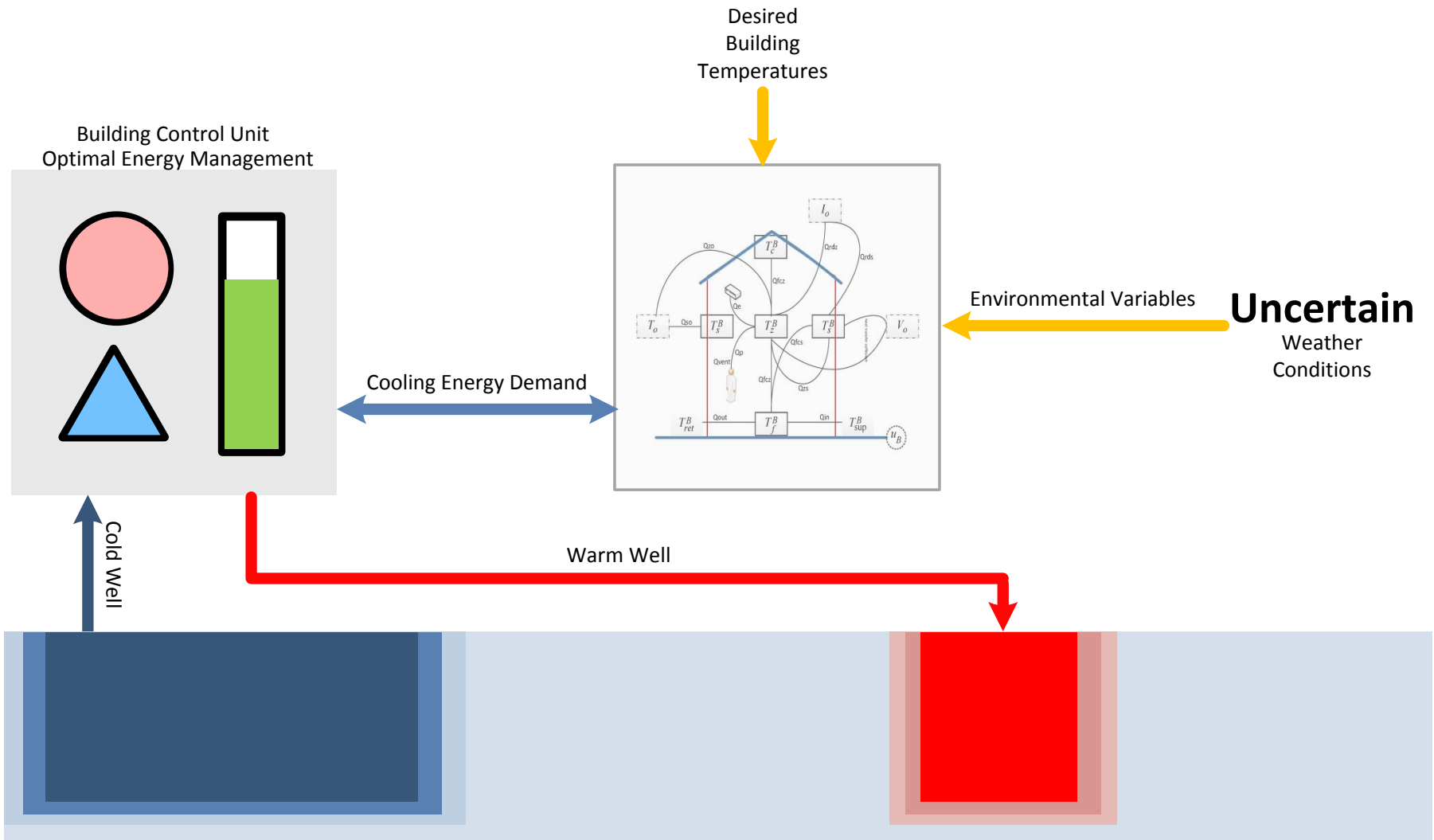

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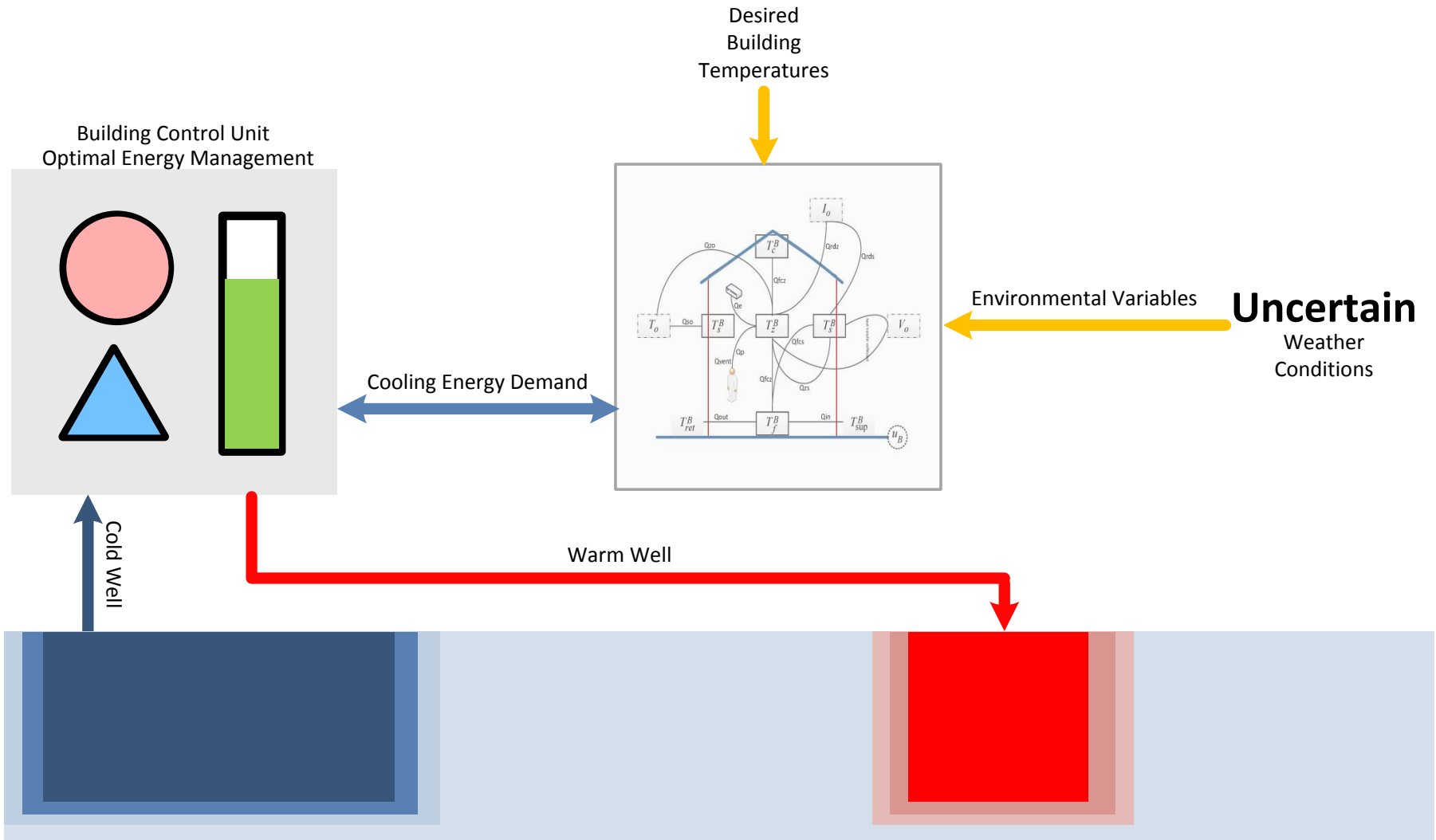

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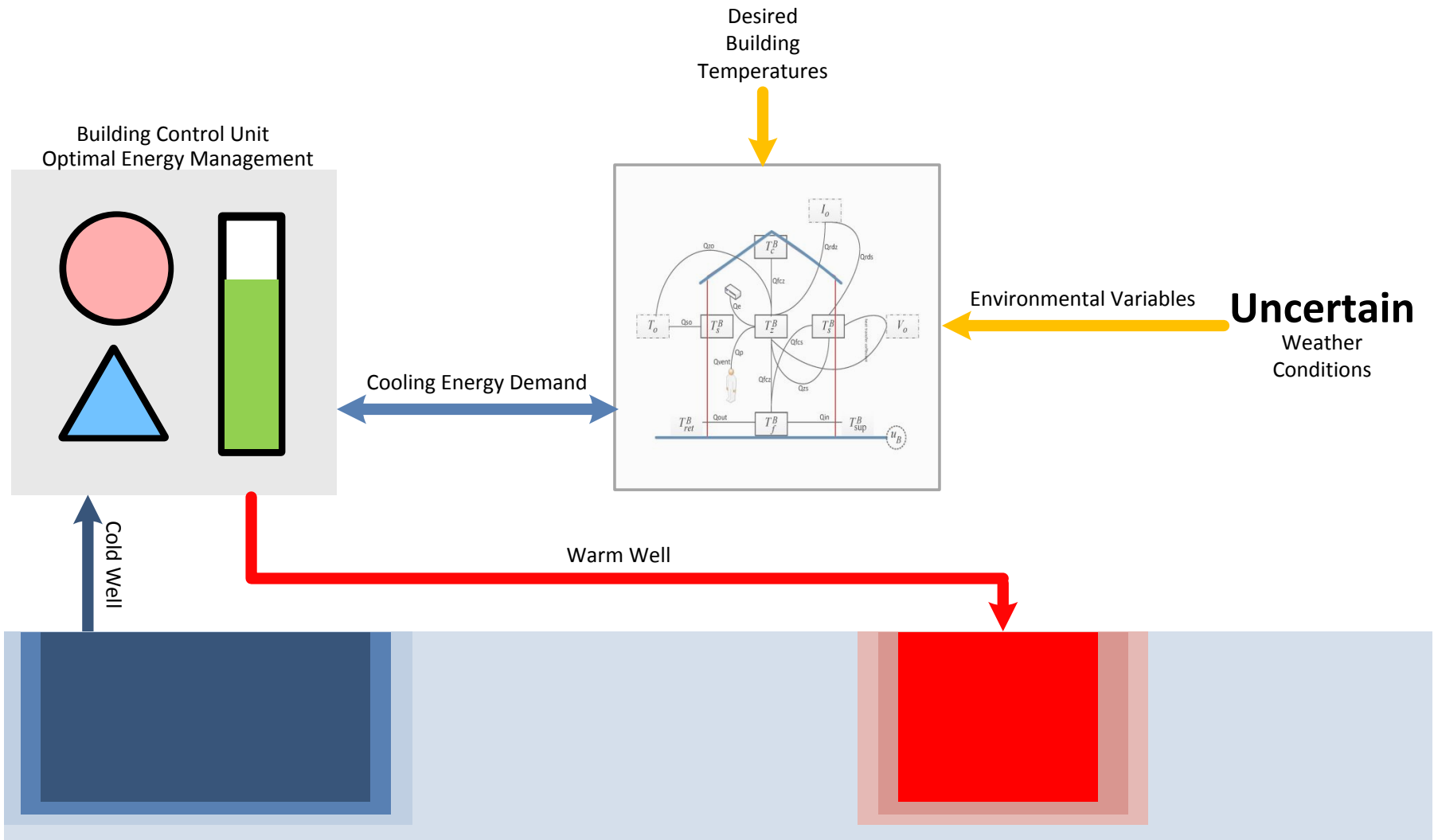

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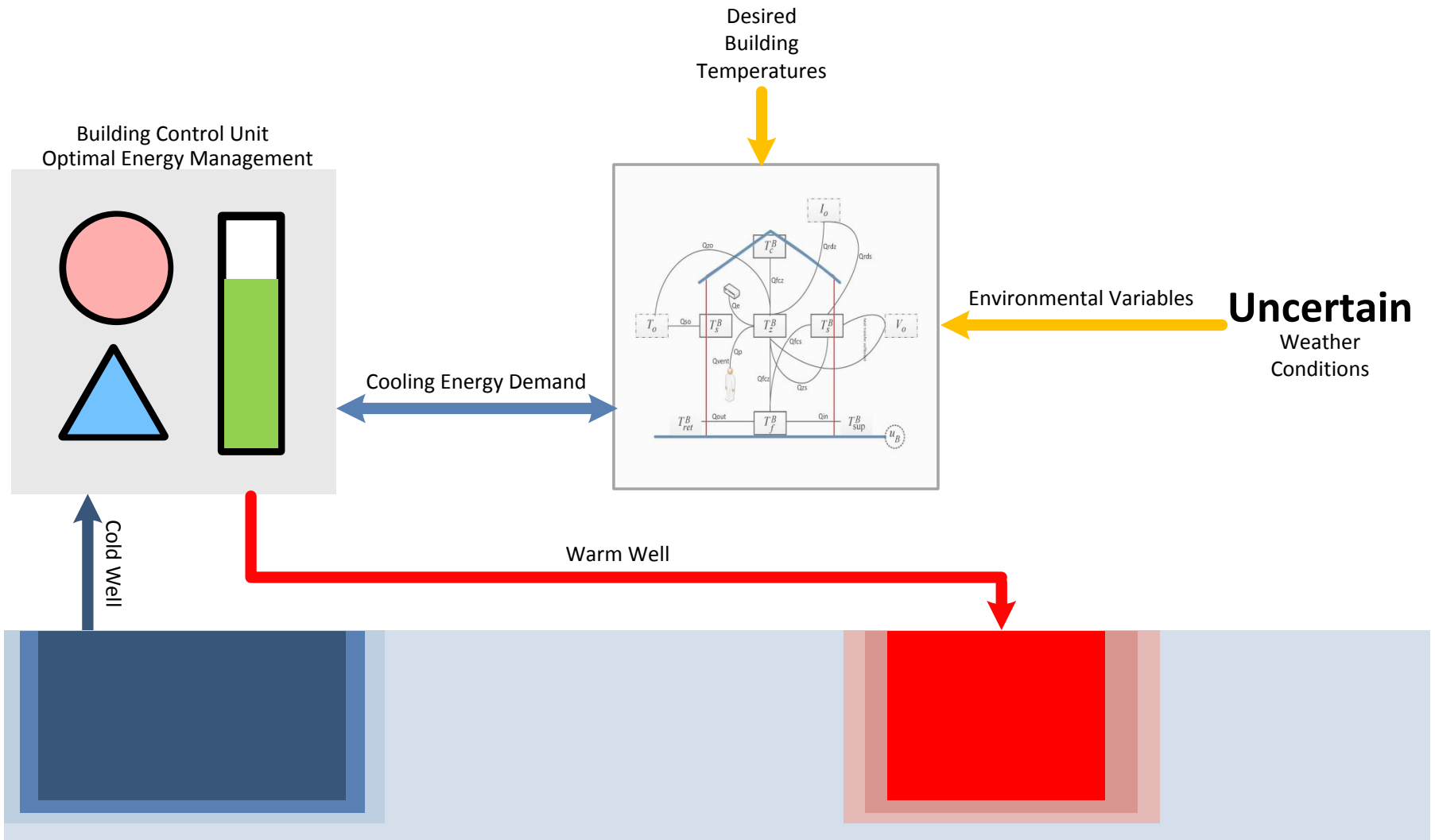

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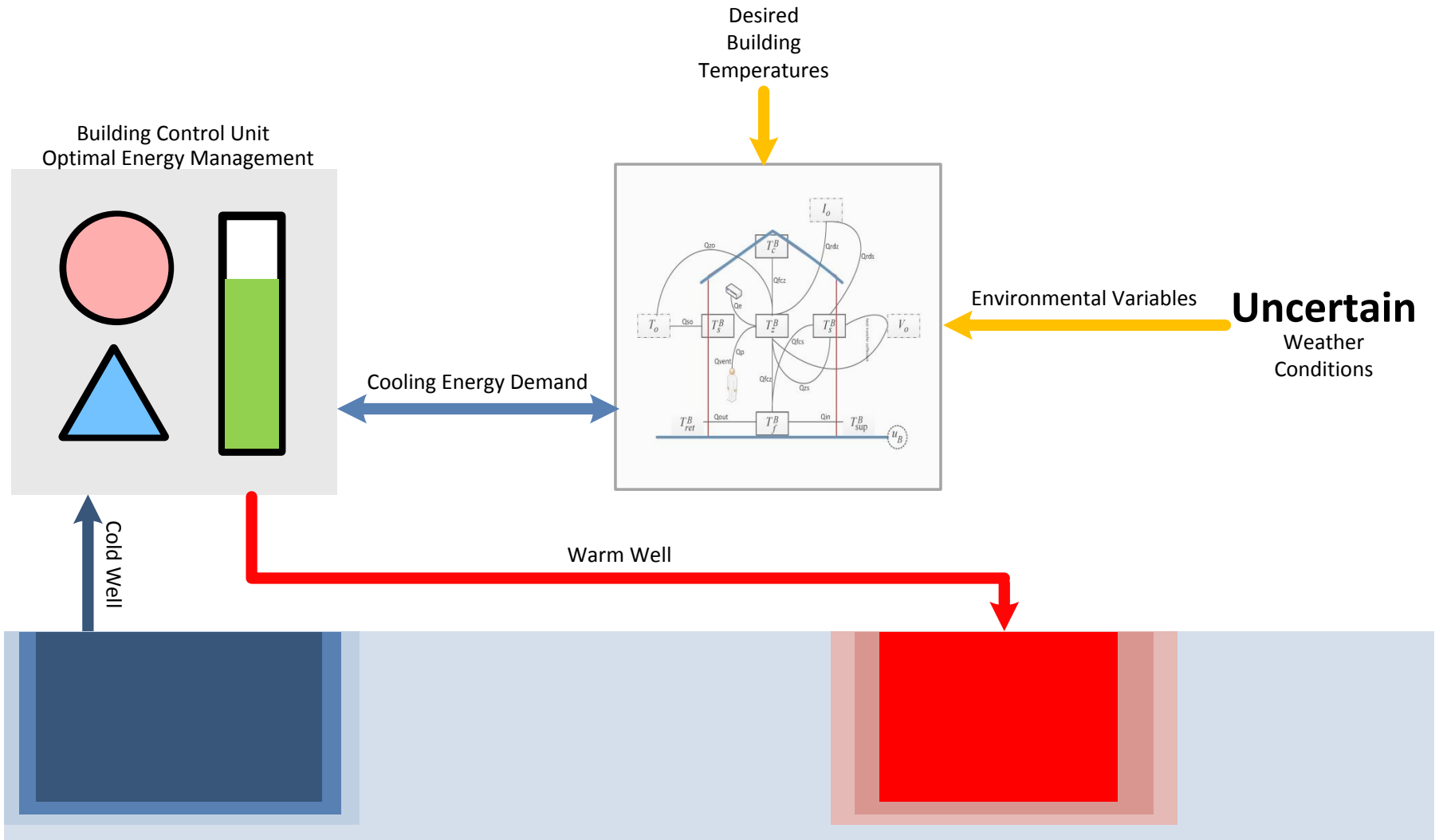

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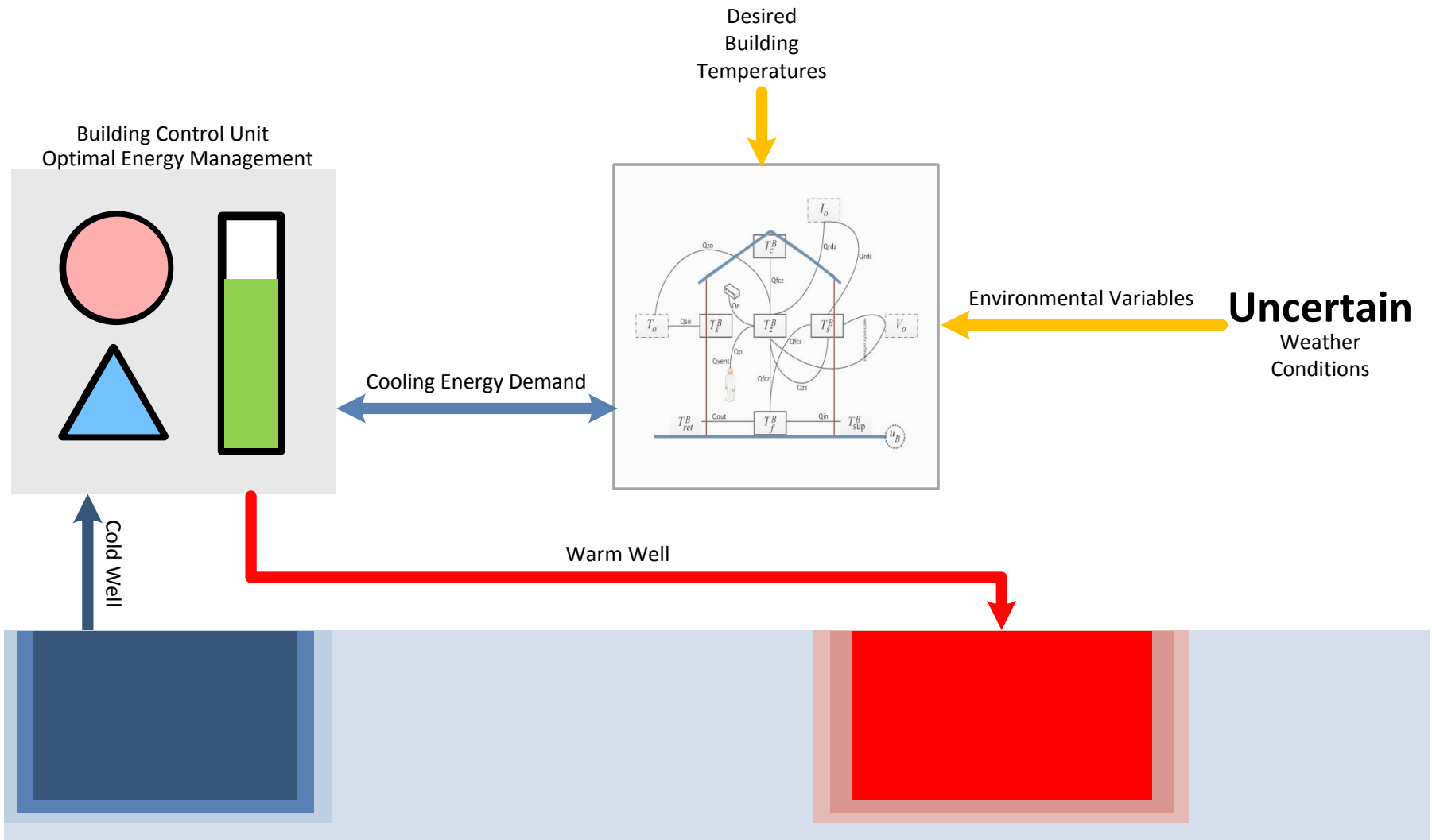

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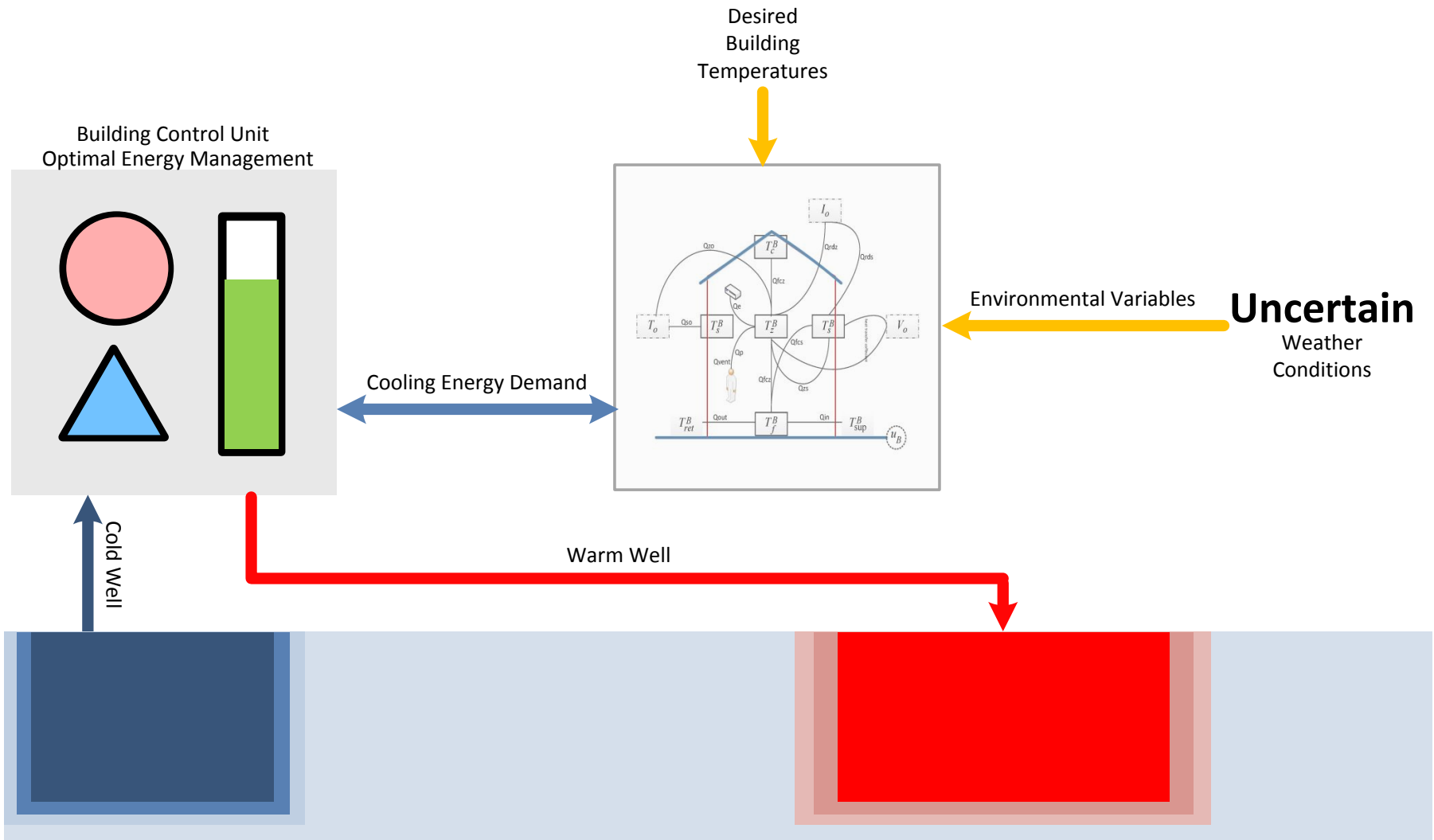

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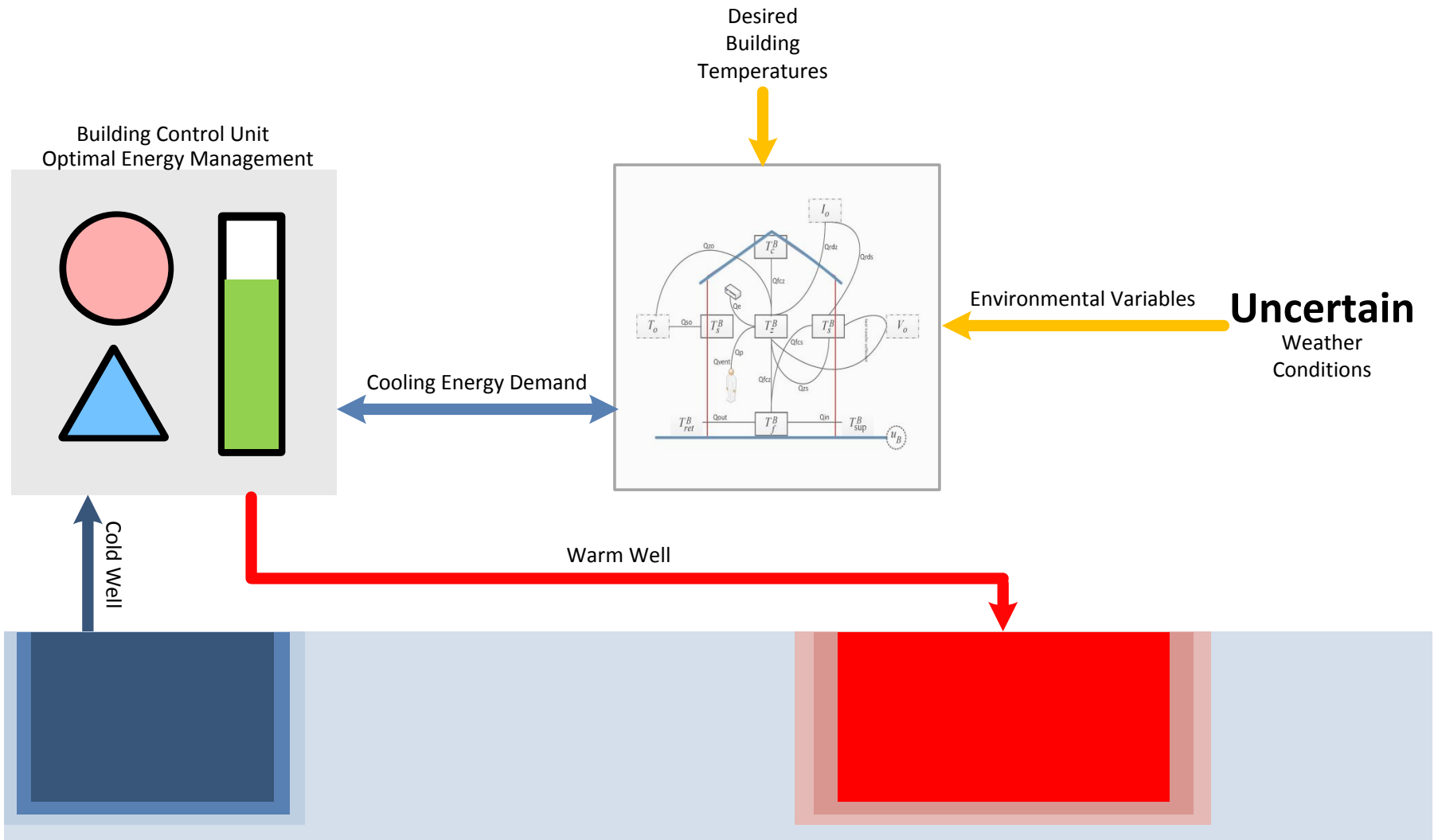

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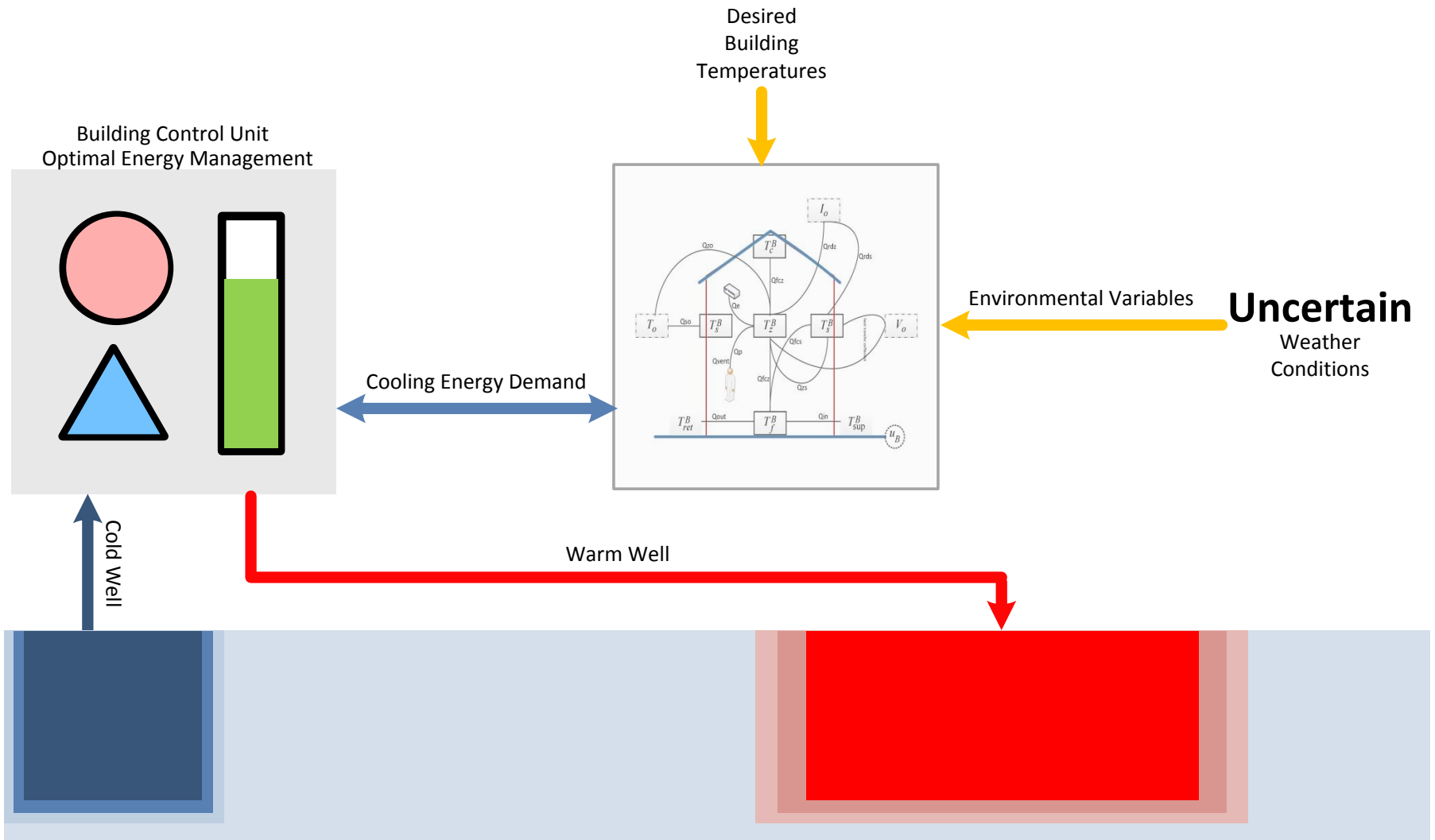

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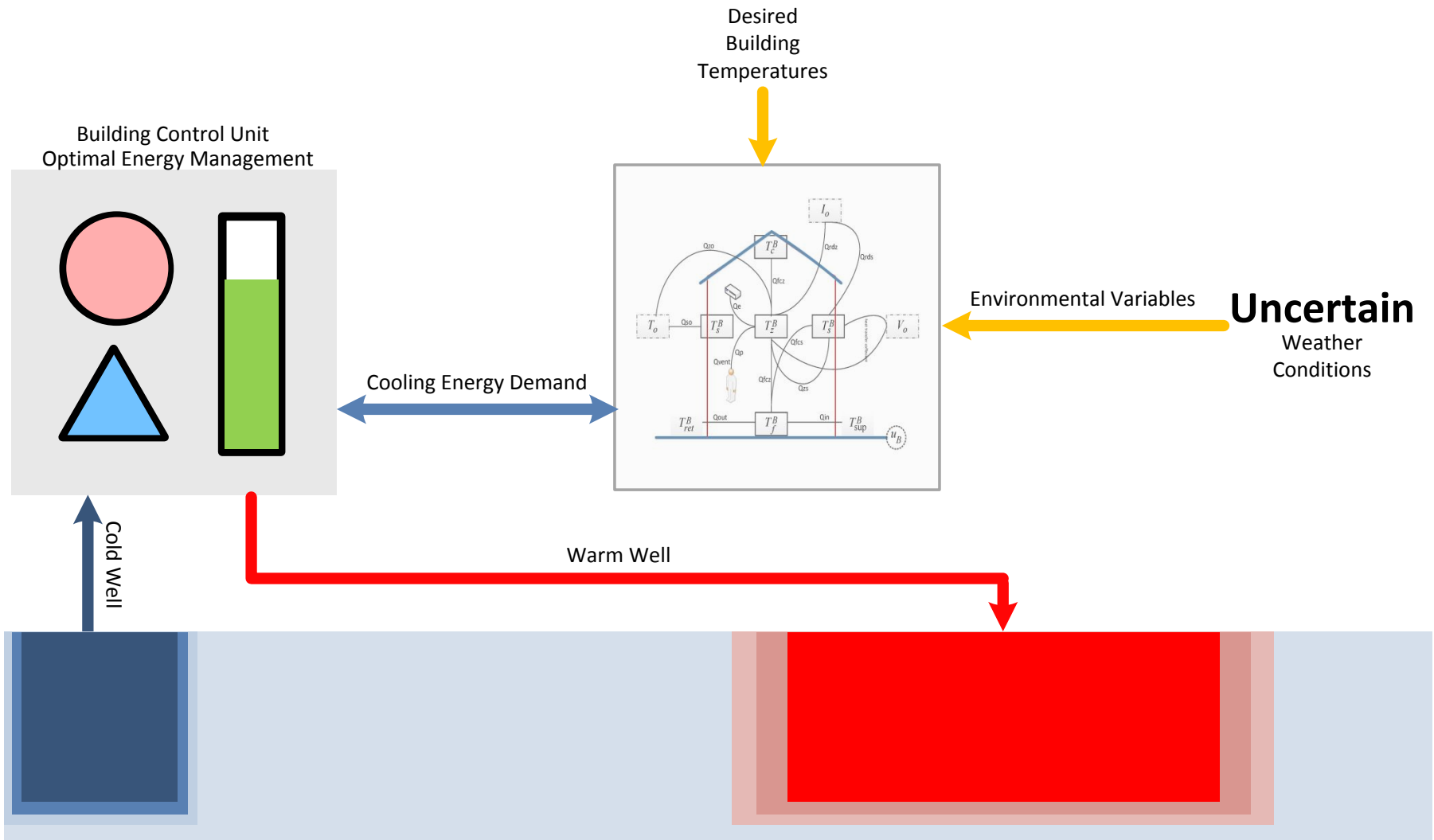

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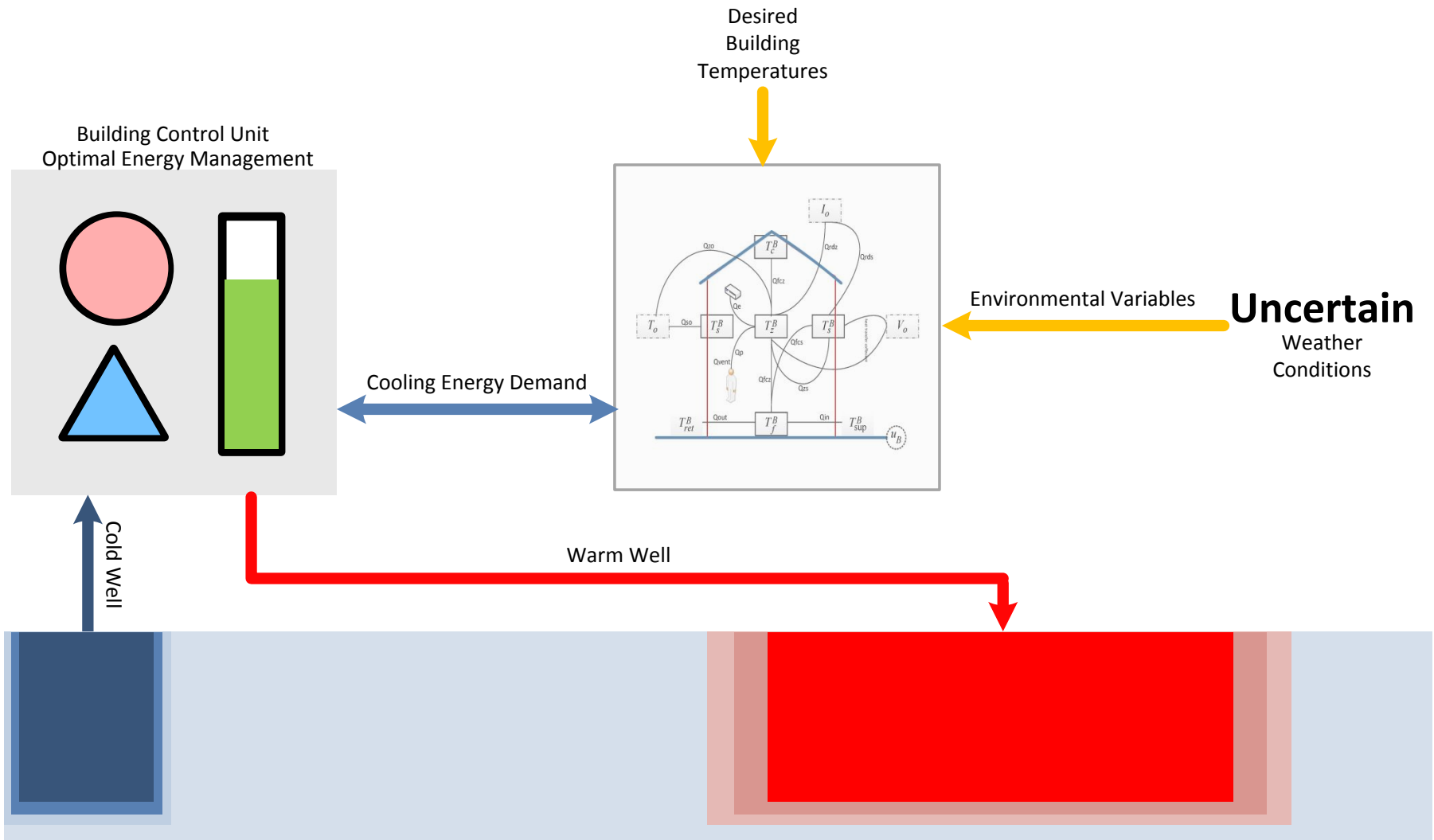

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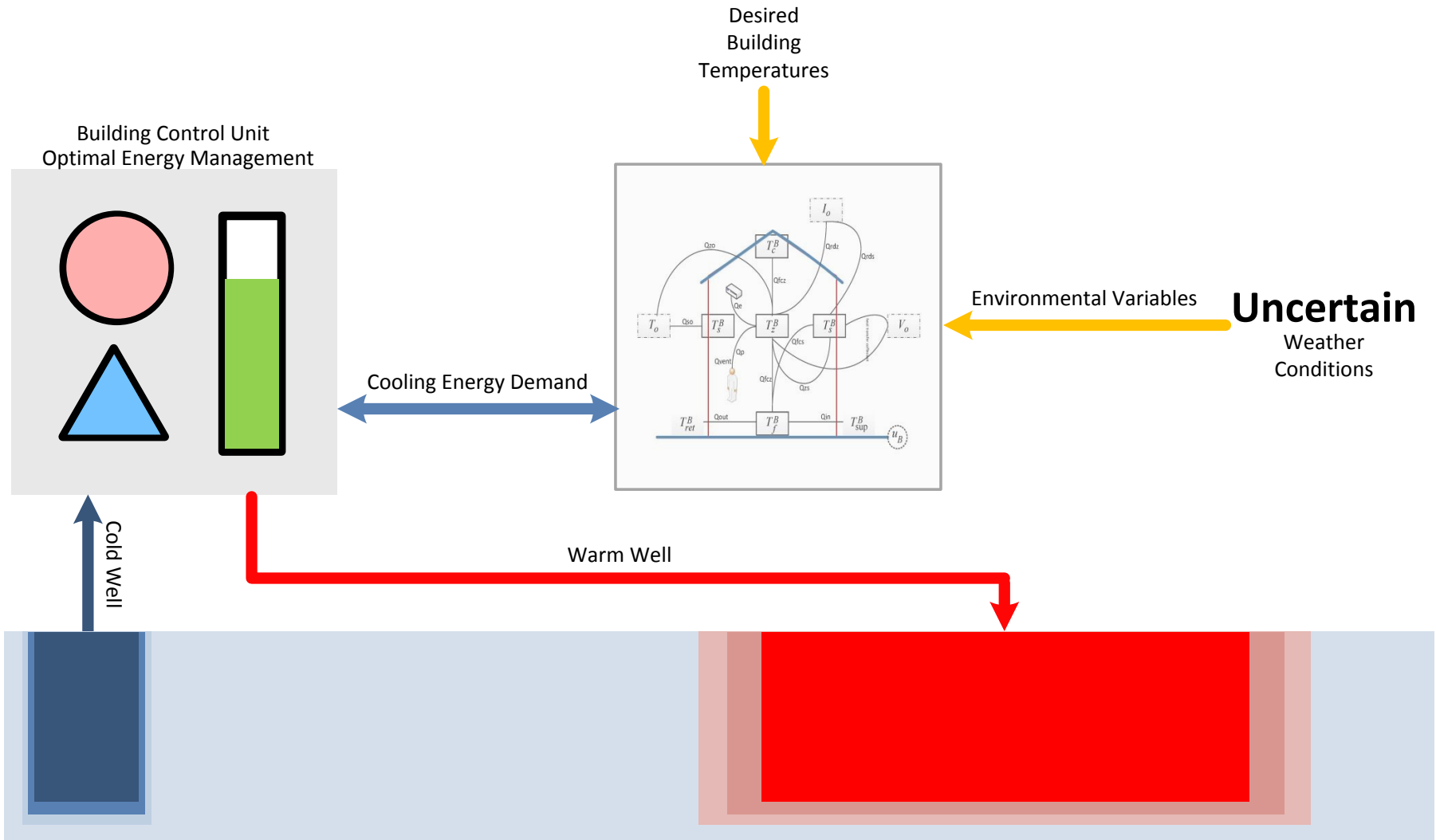

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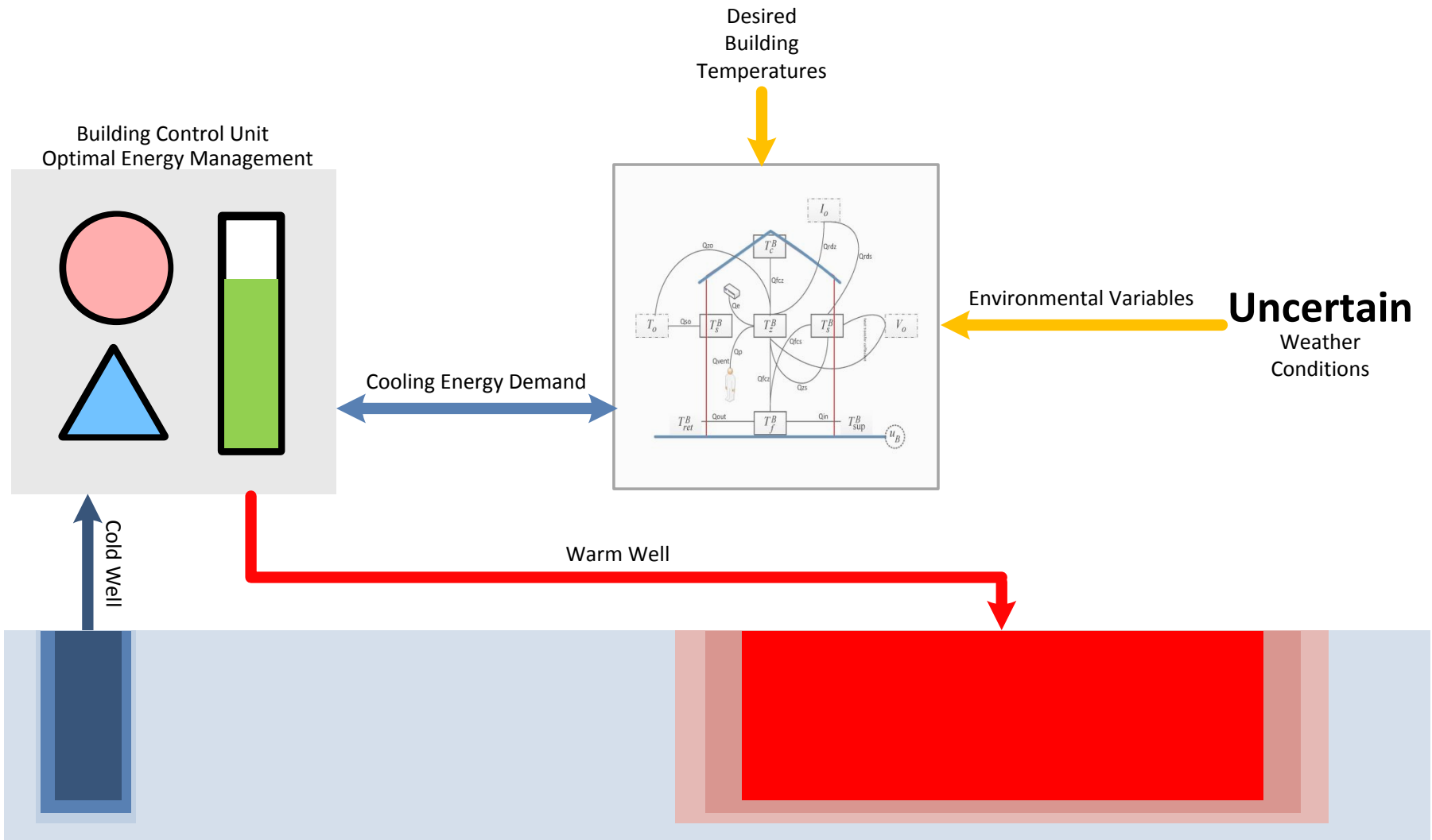

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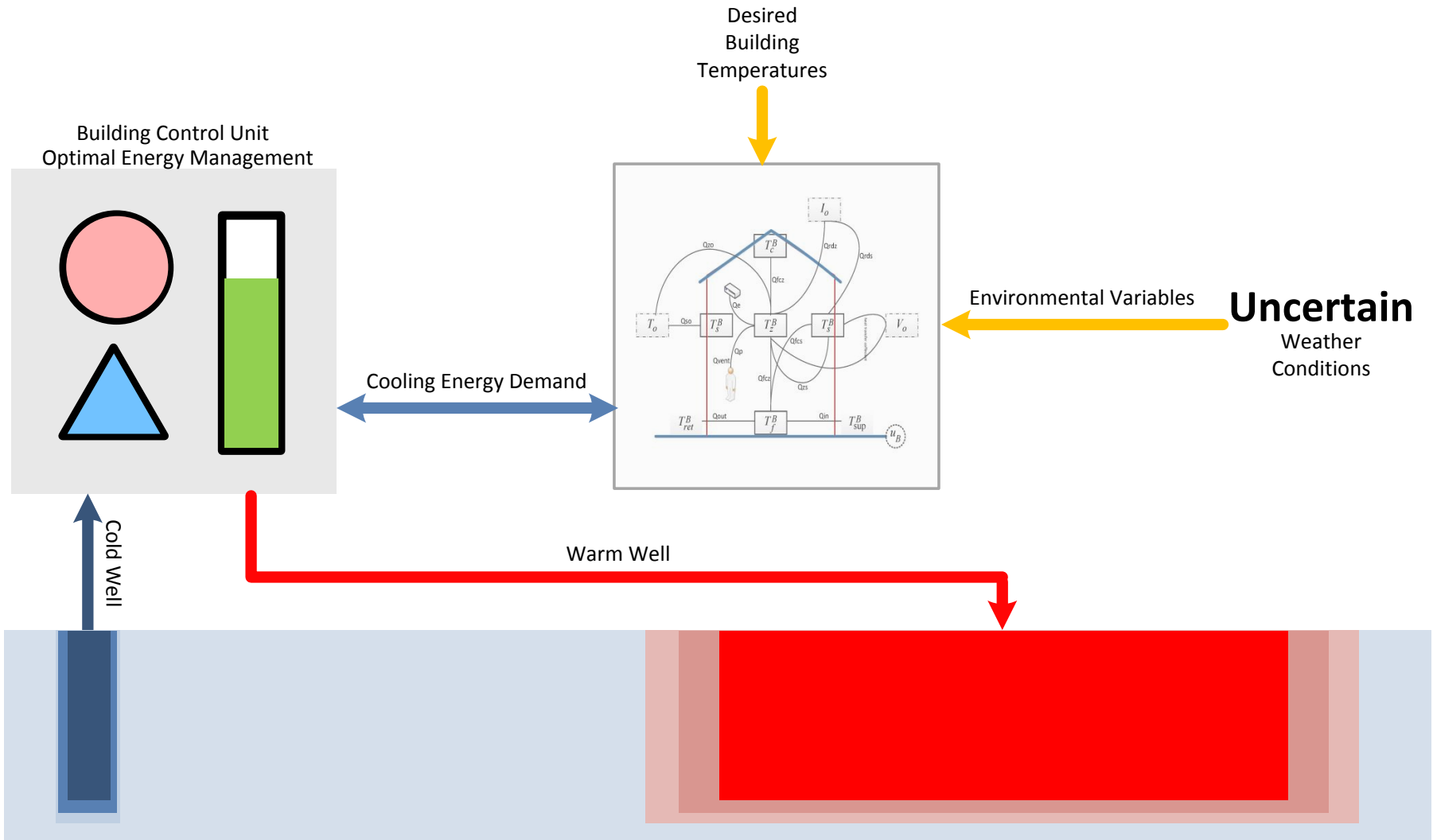

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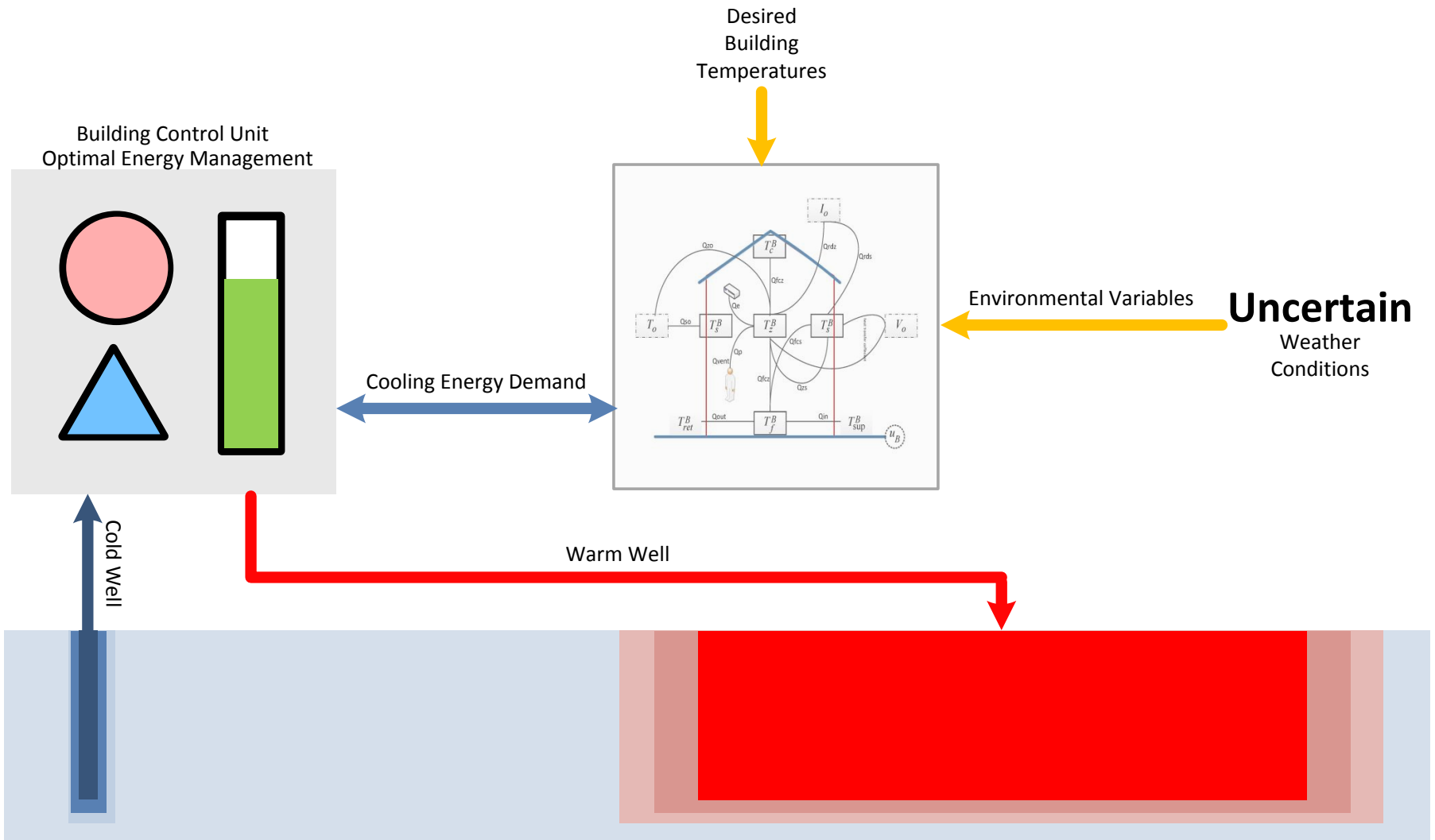

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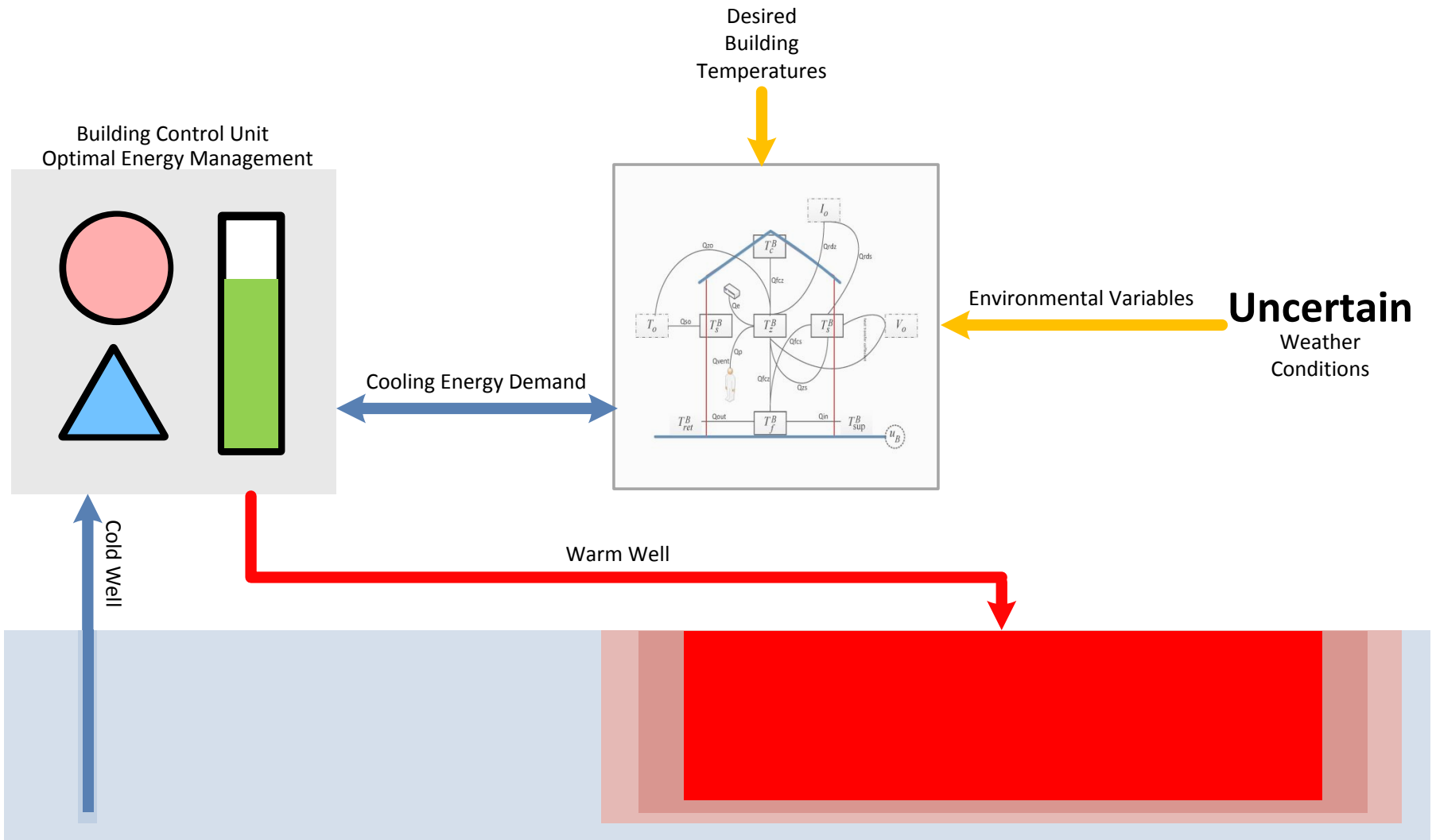
Proposed Practical Predictive Dynamics: Cooling Mode



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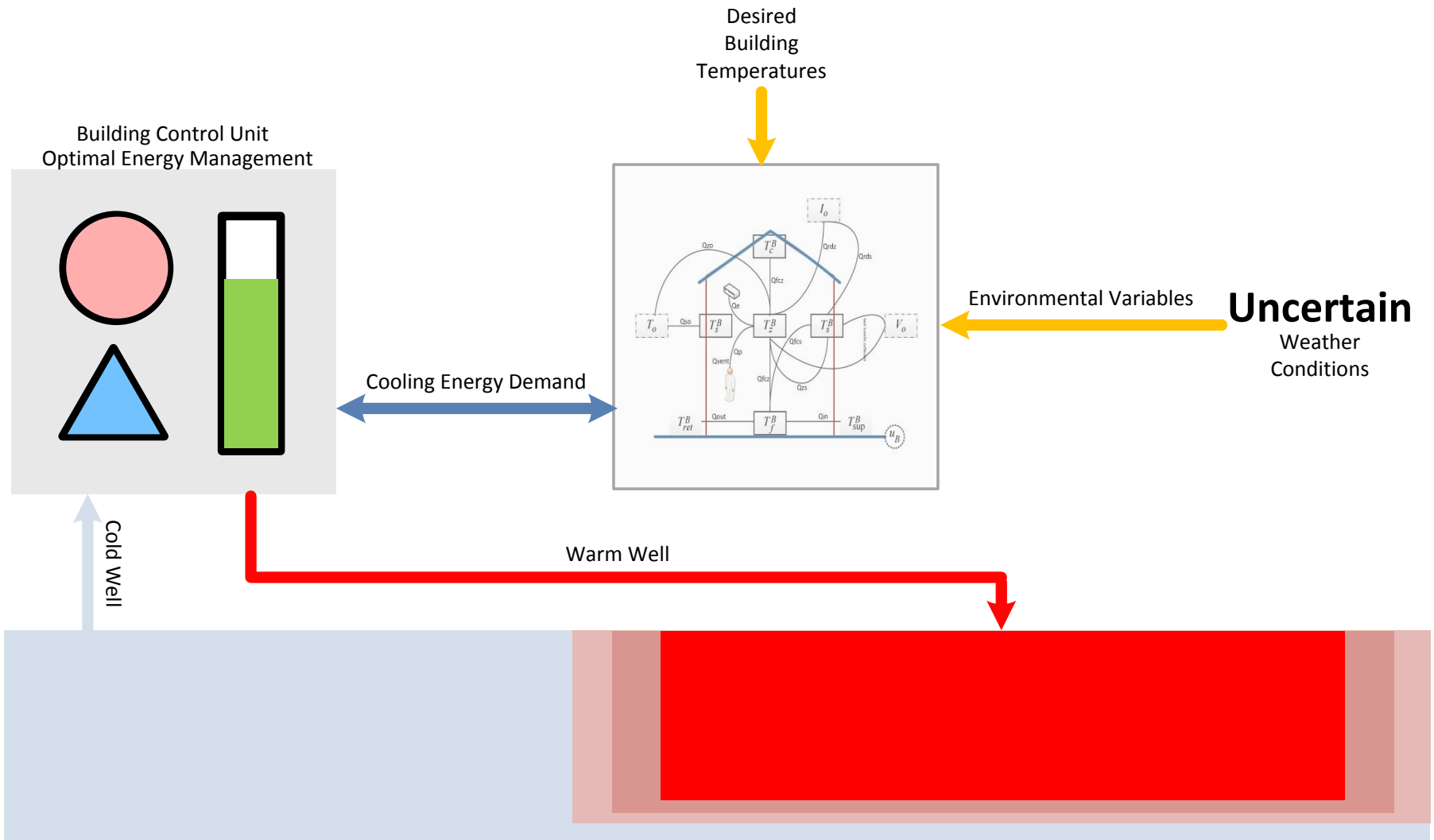

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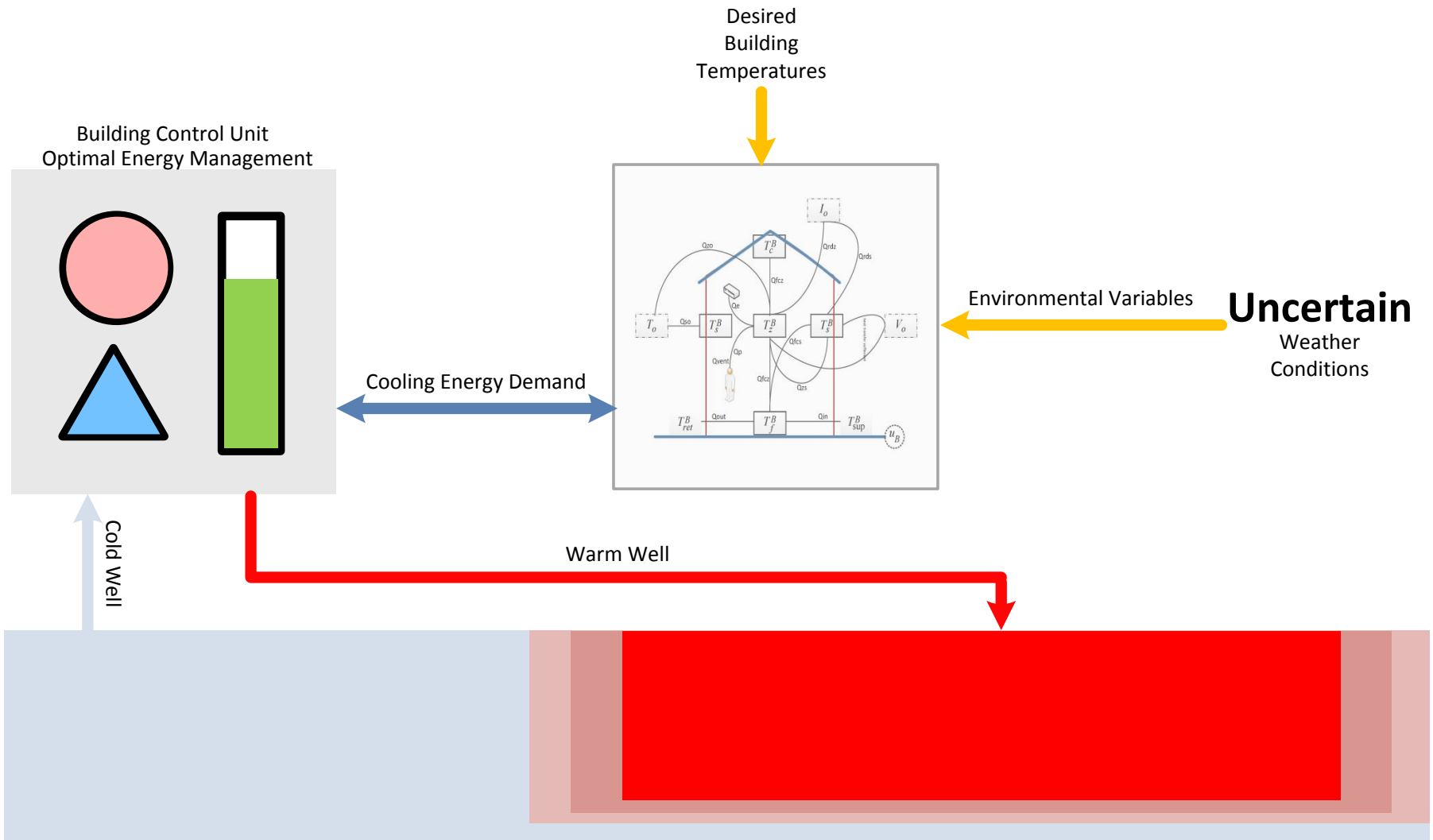

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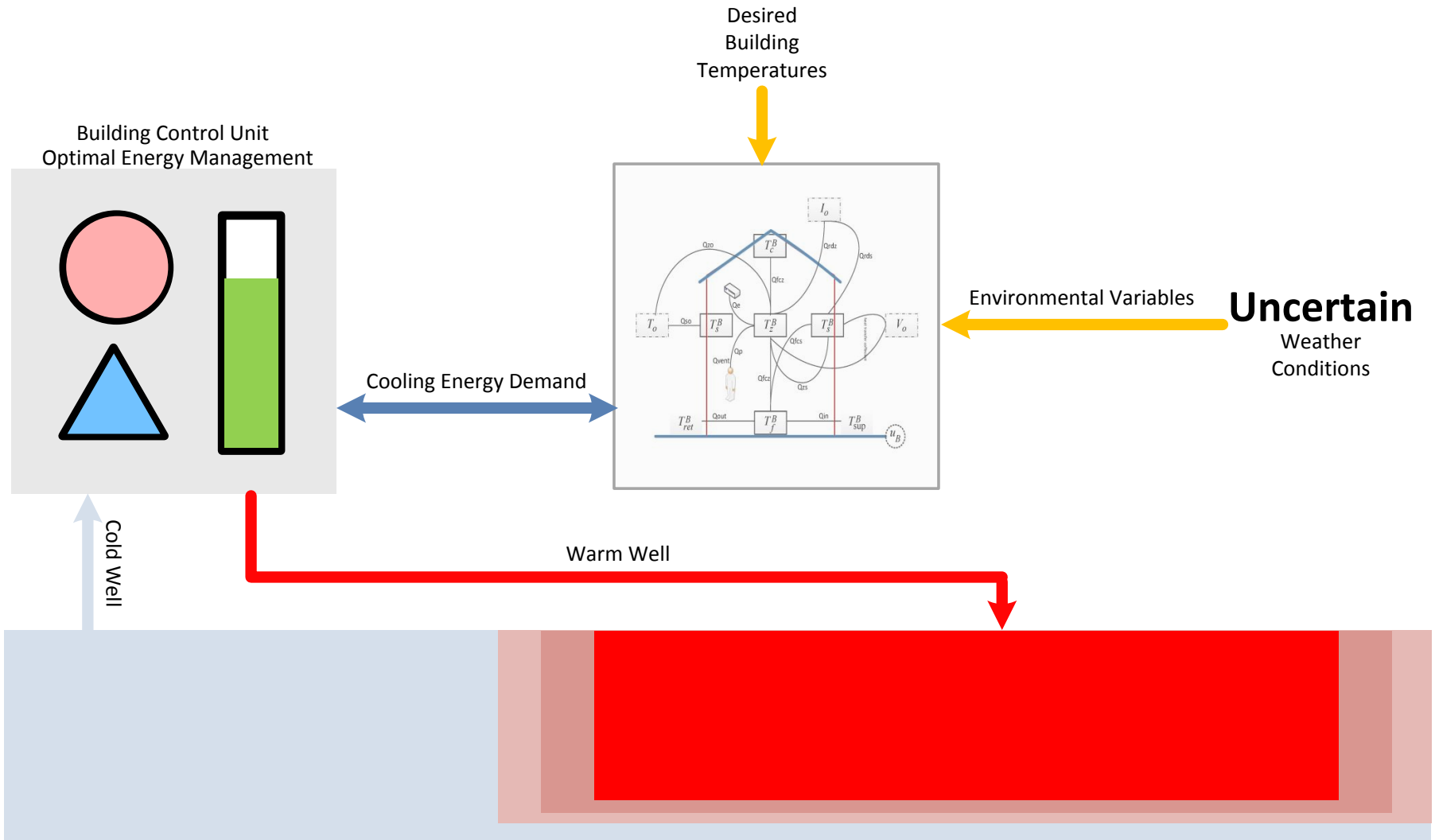

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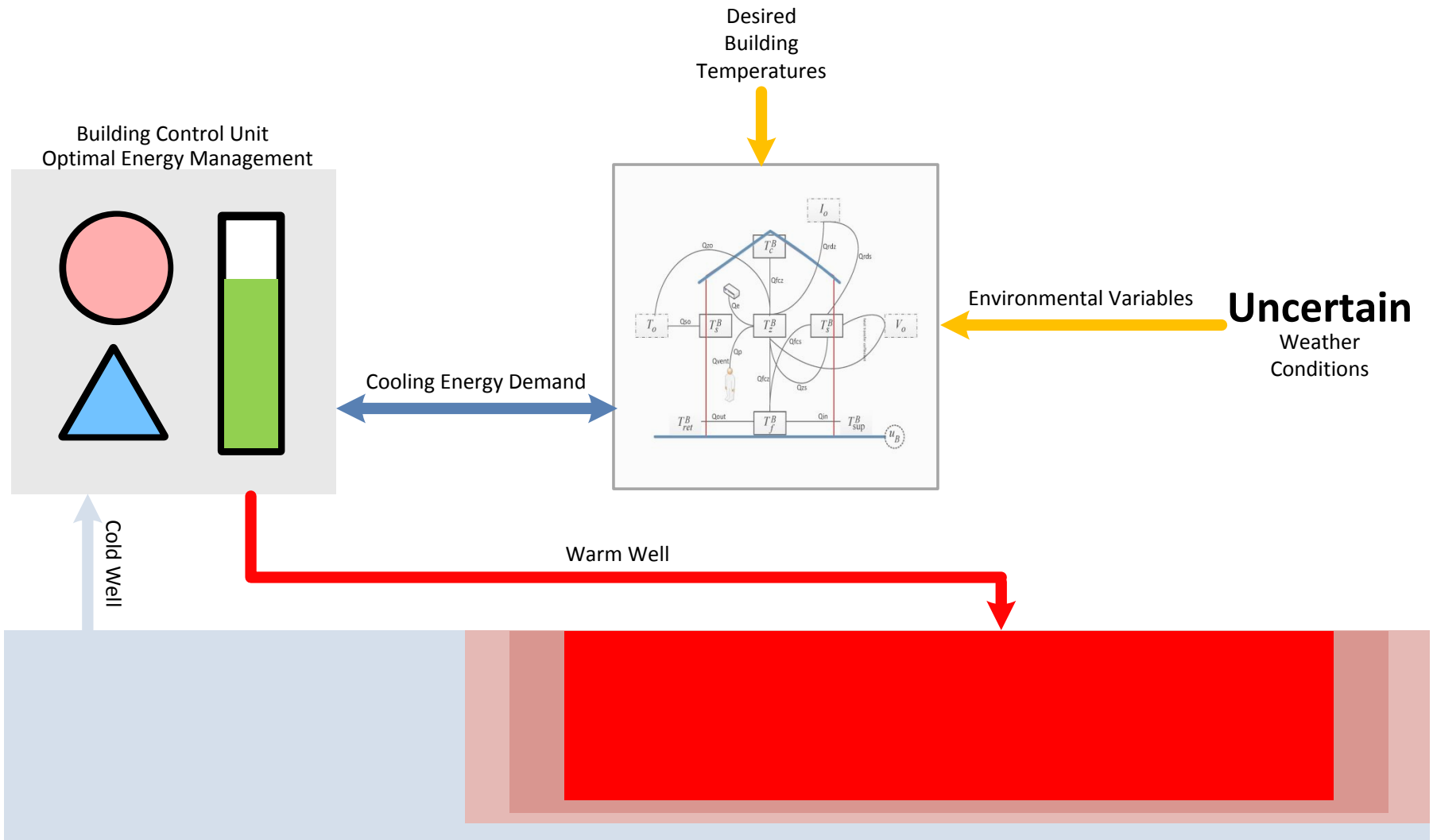

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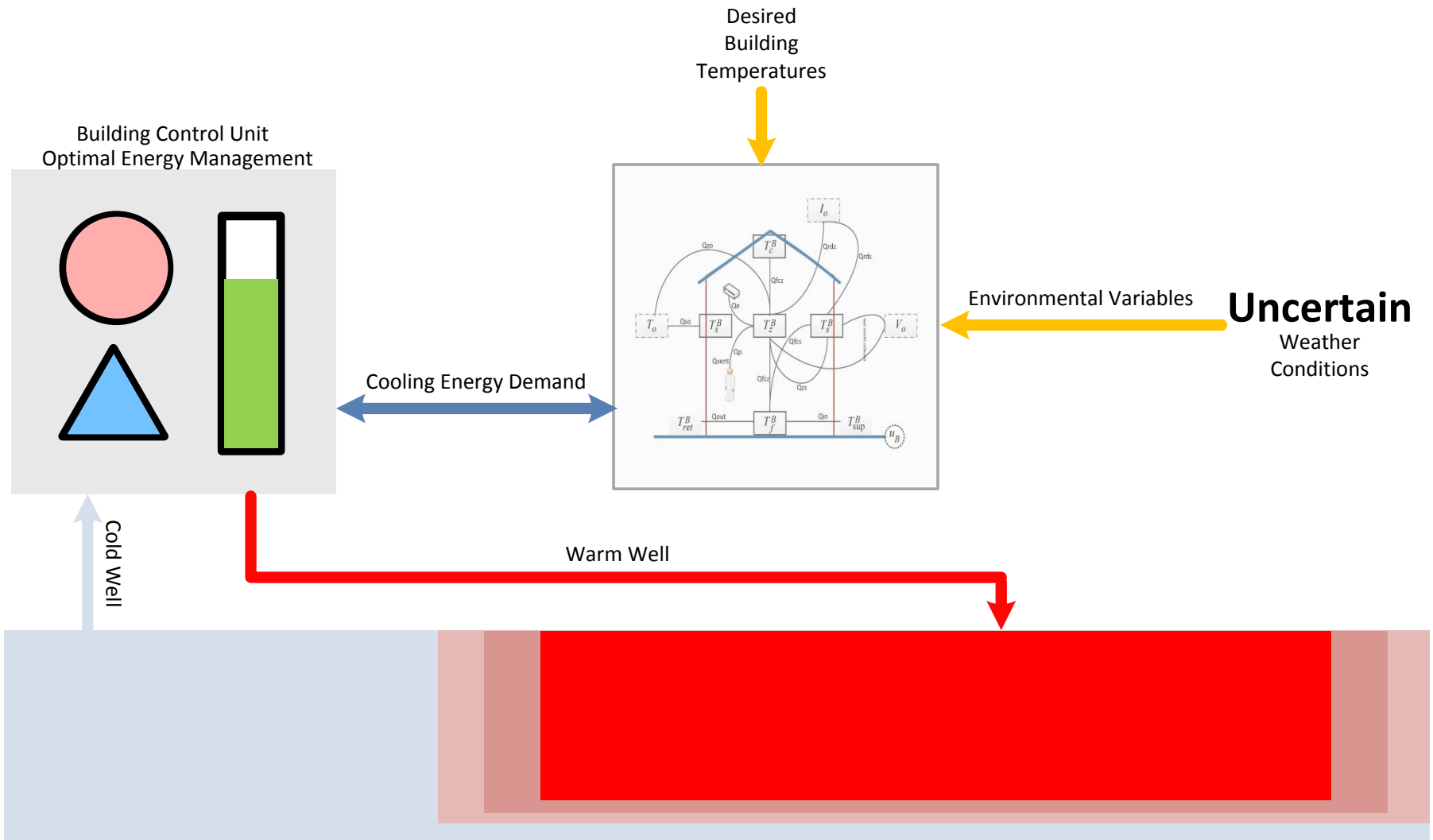

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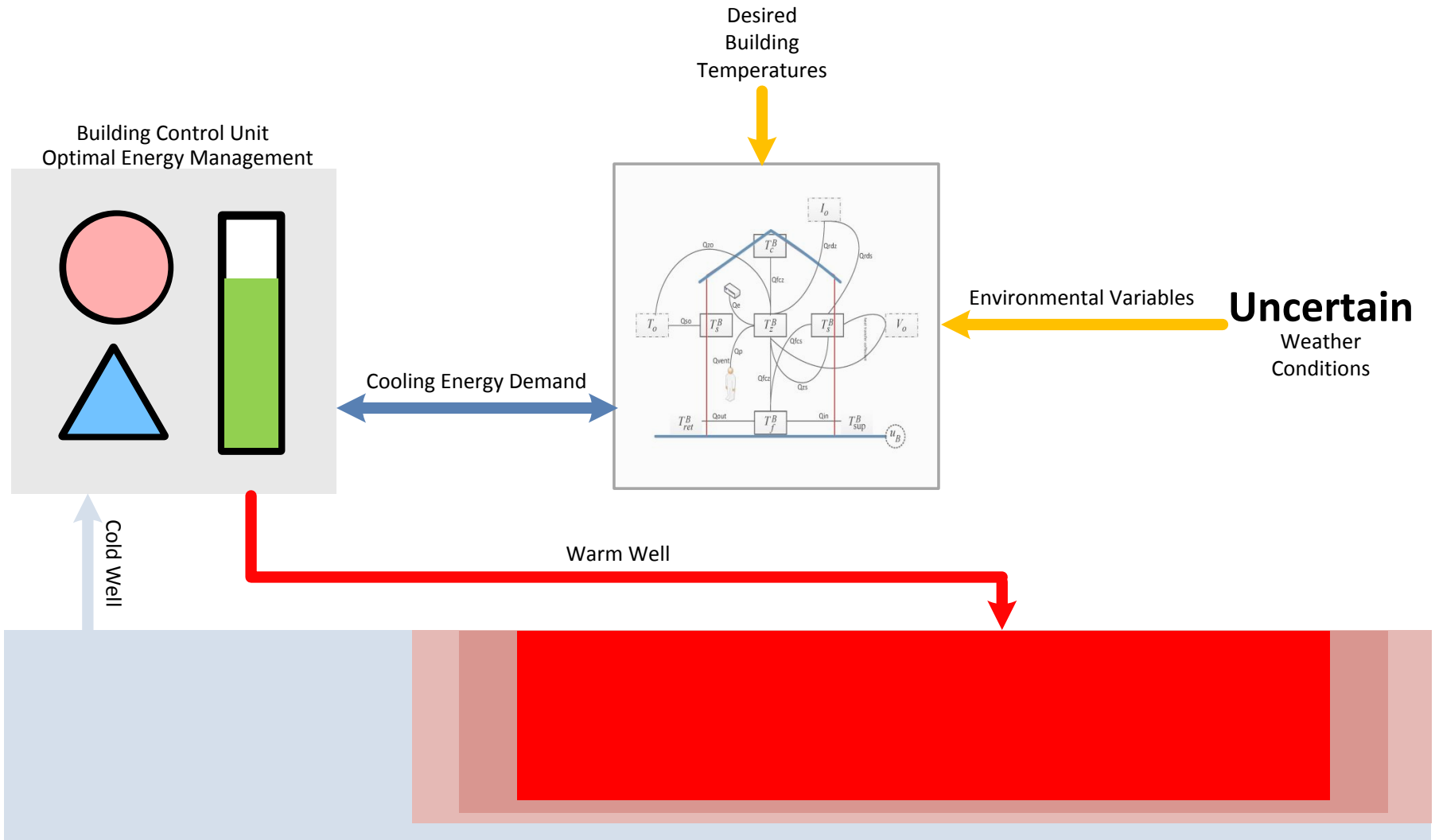

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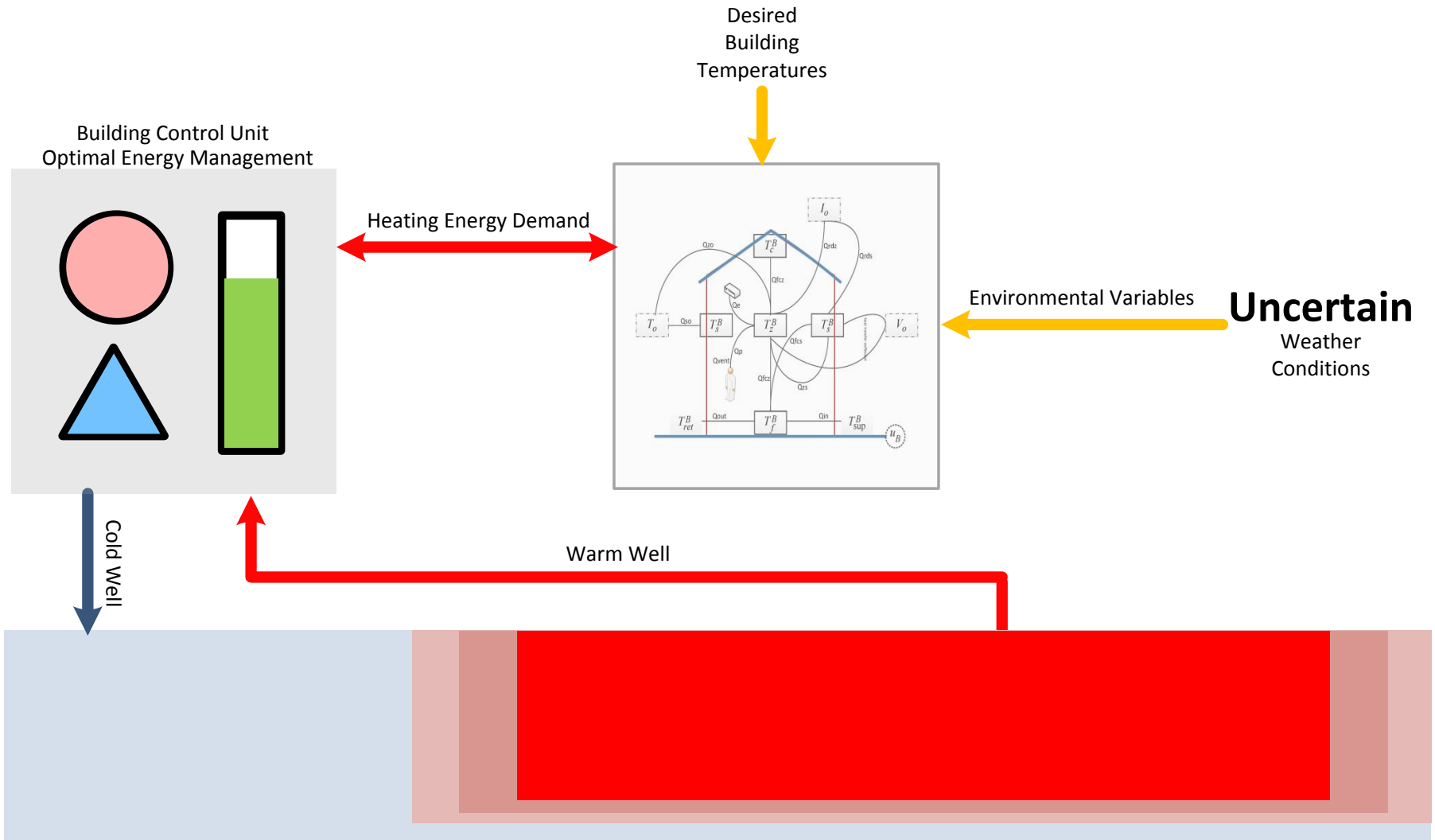

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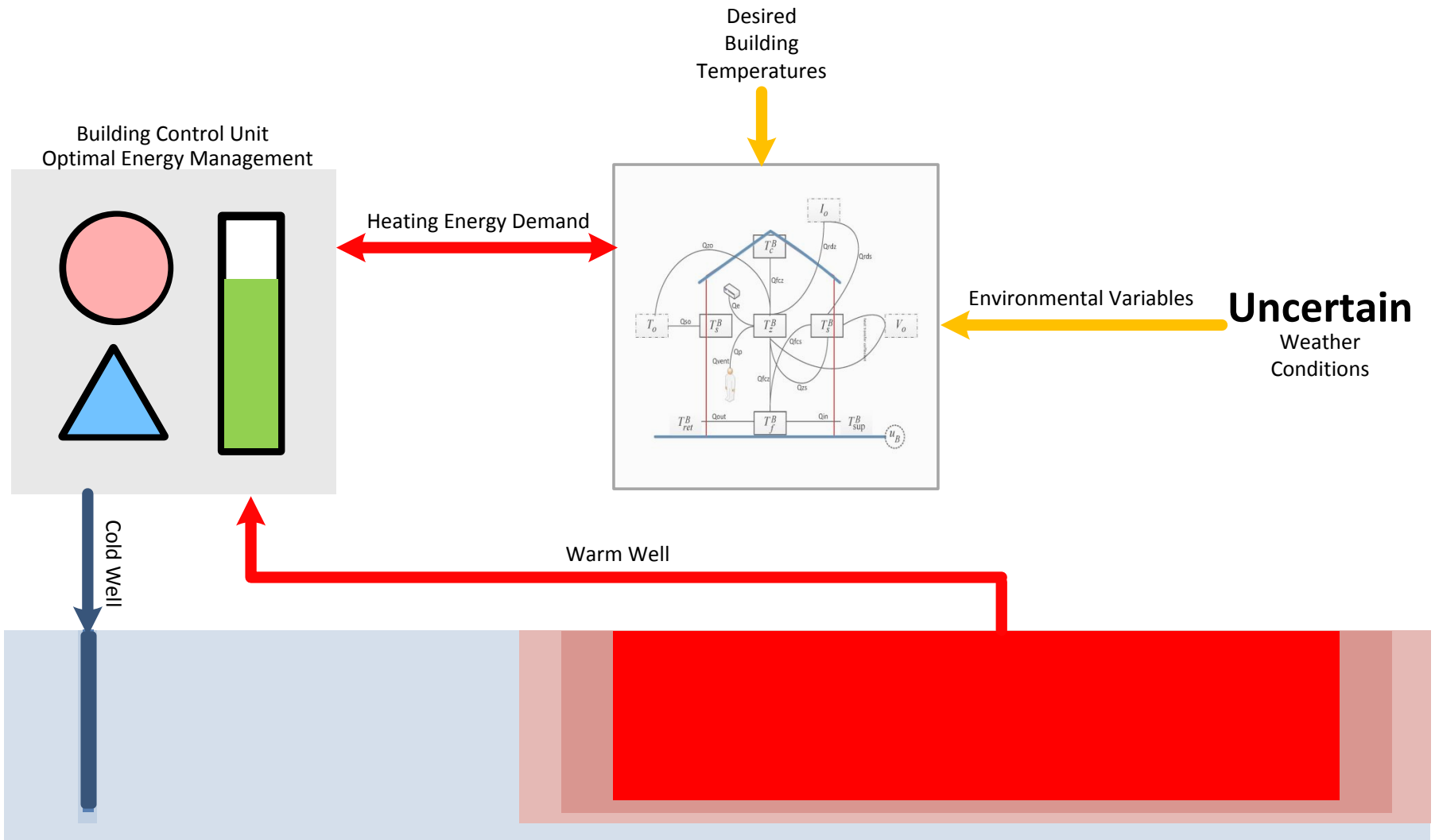

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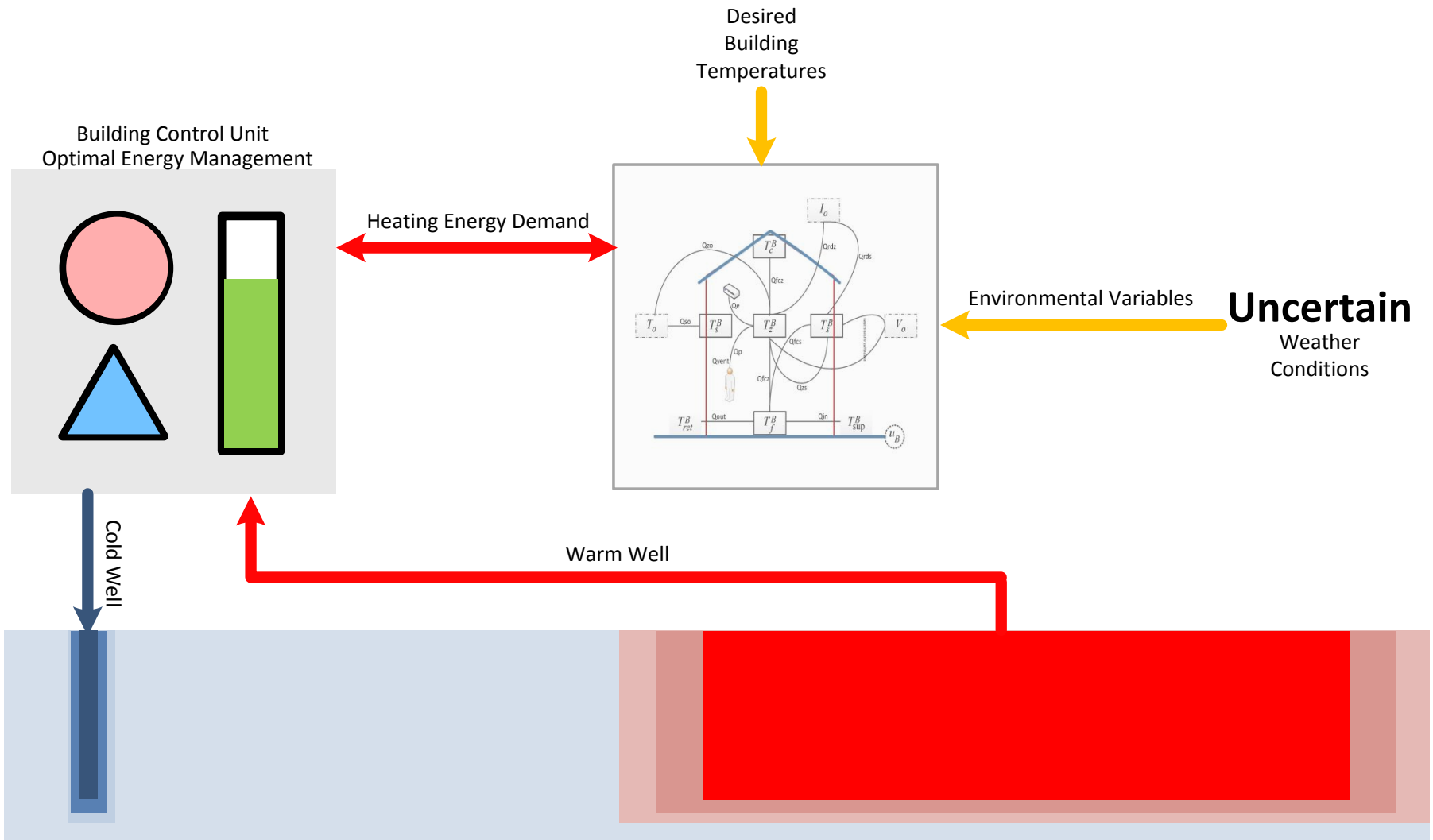

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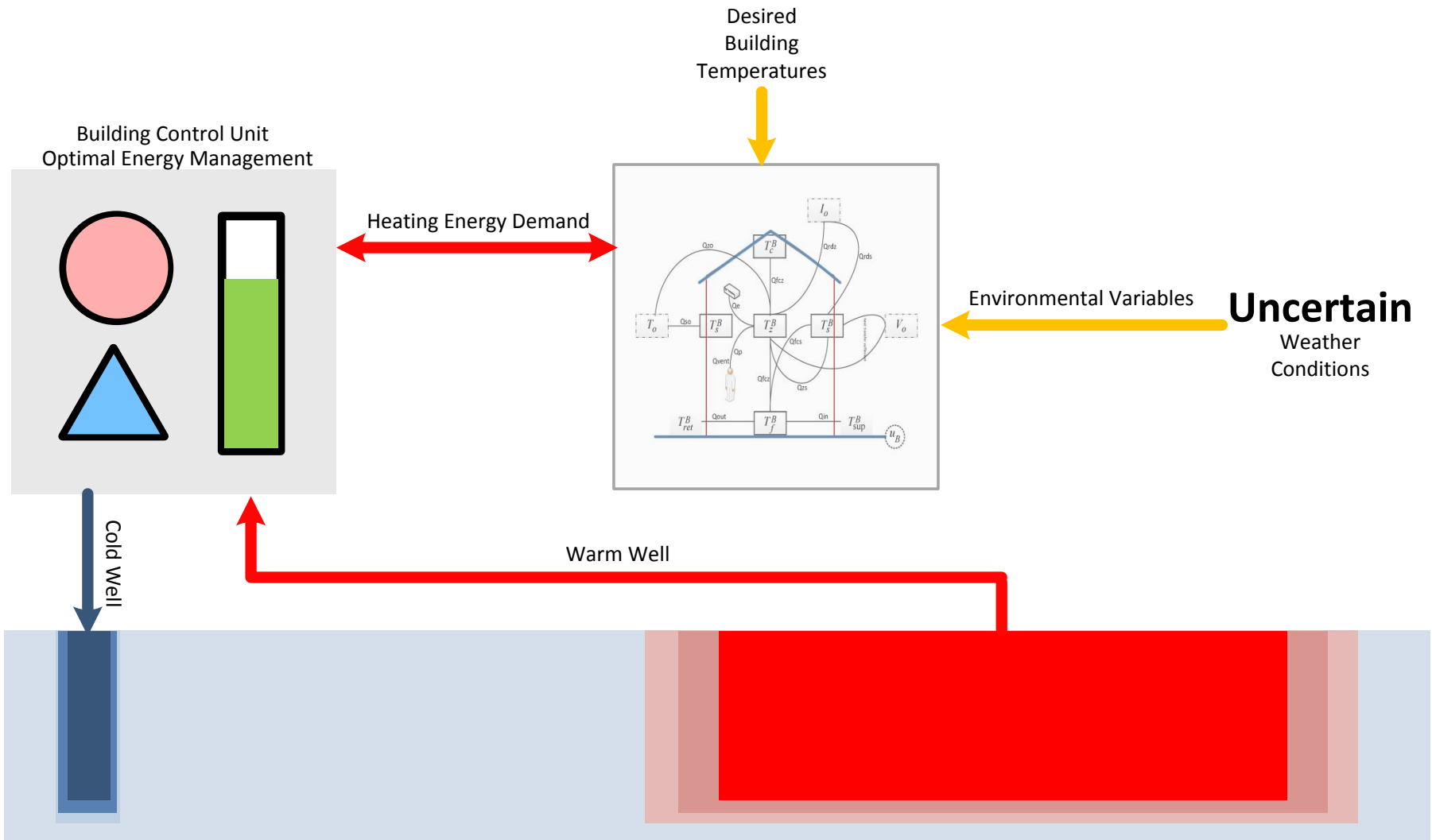

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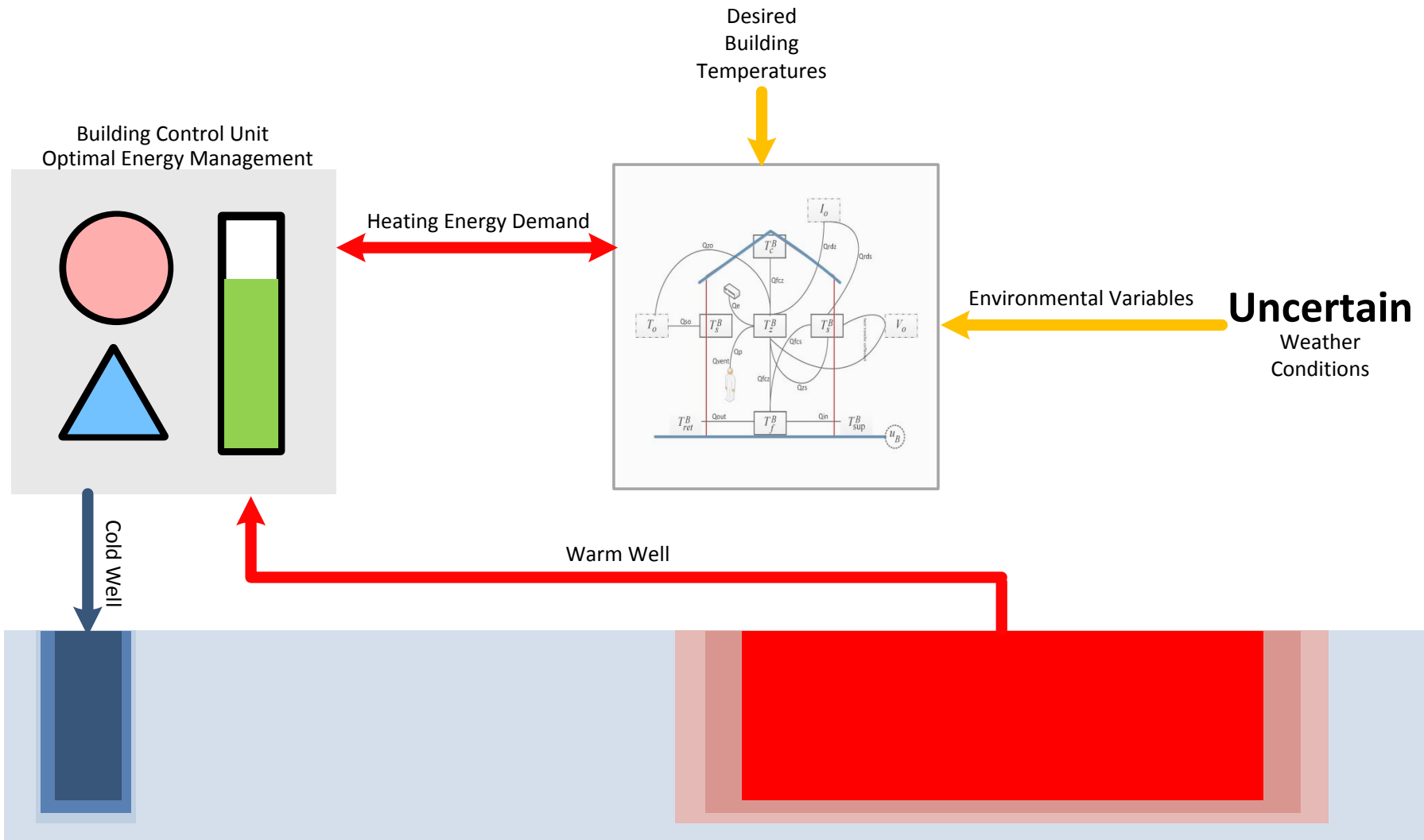

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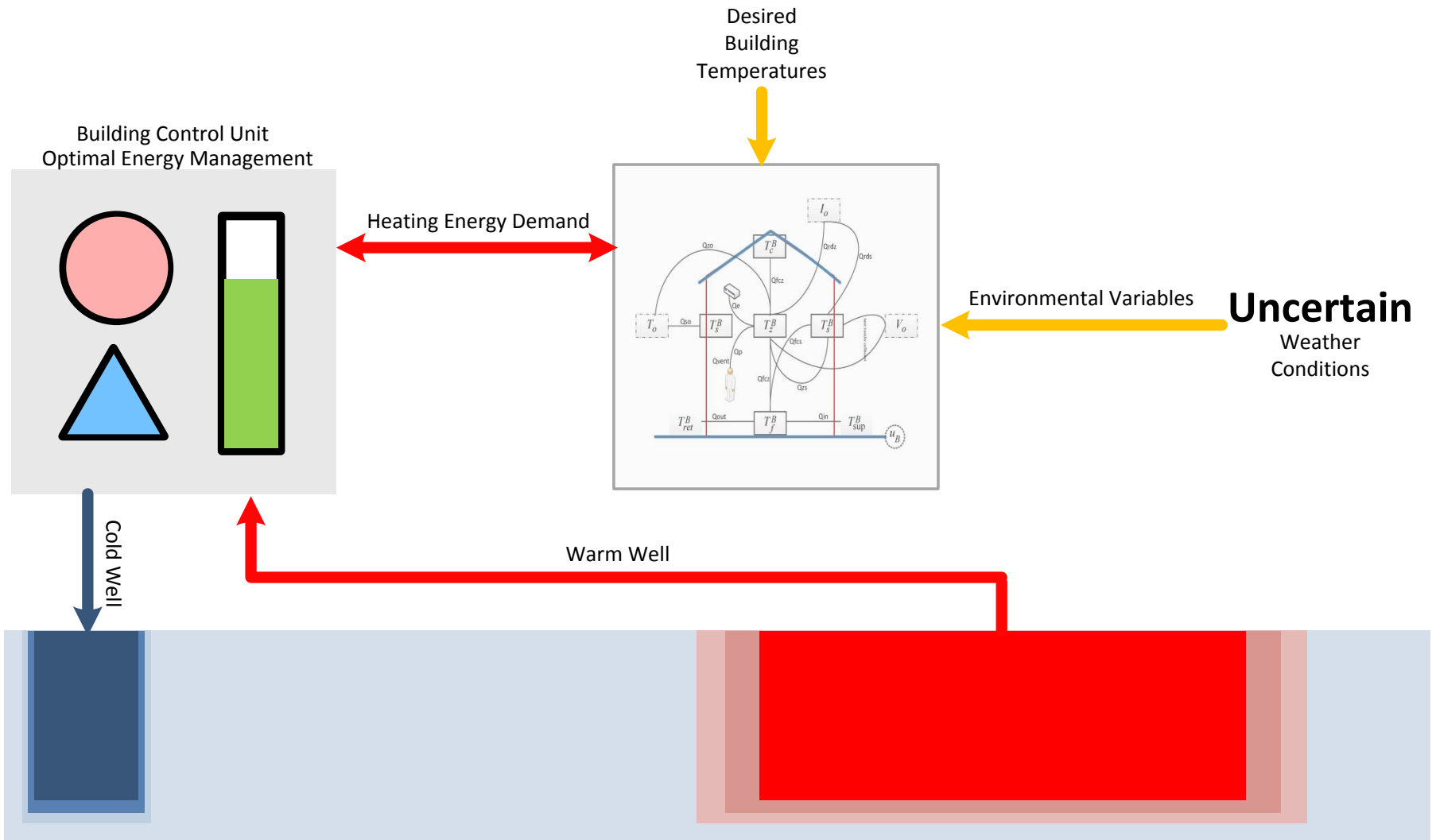

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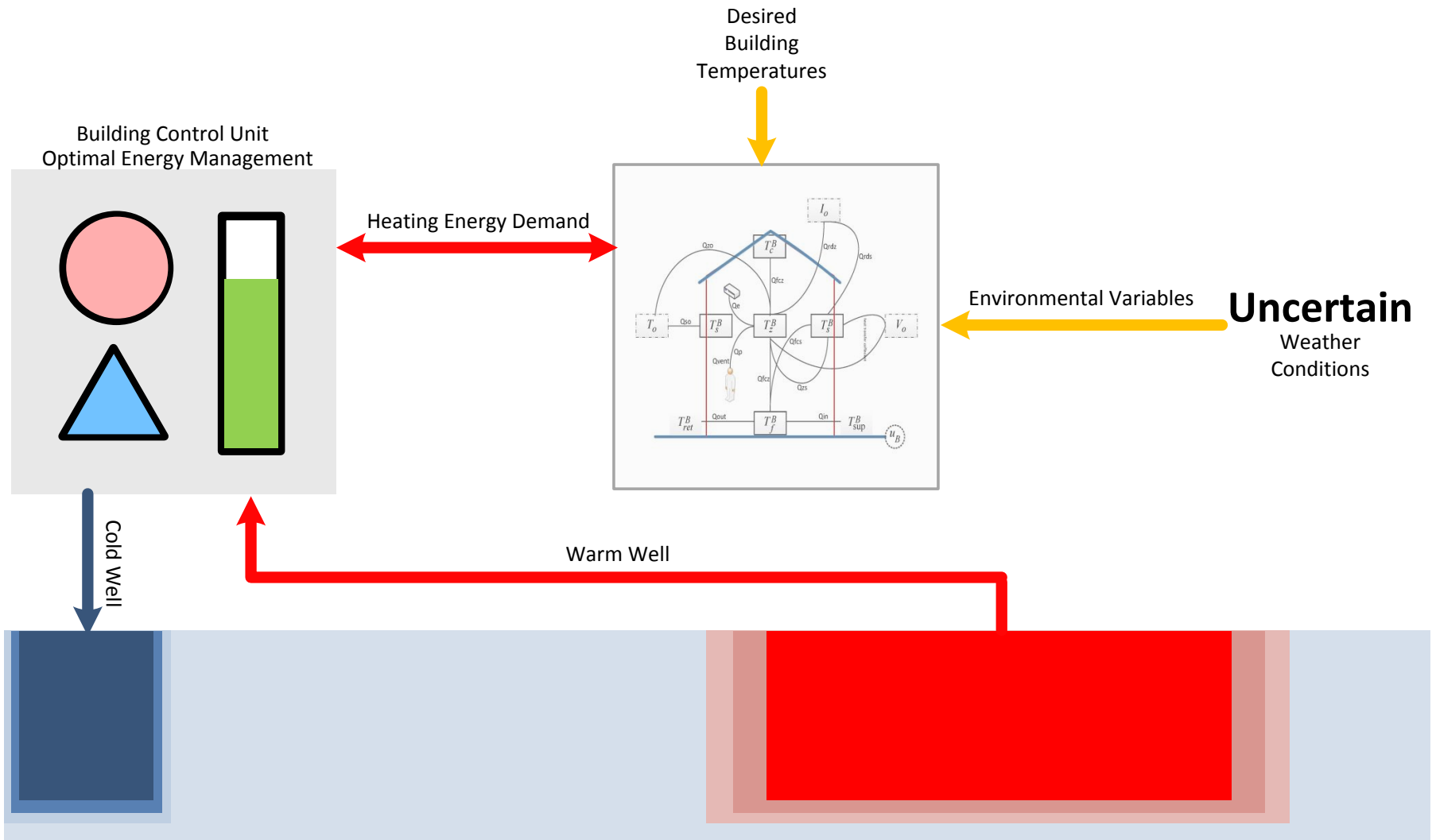

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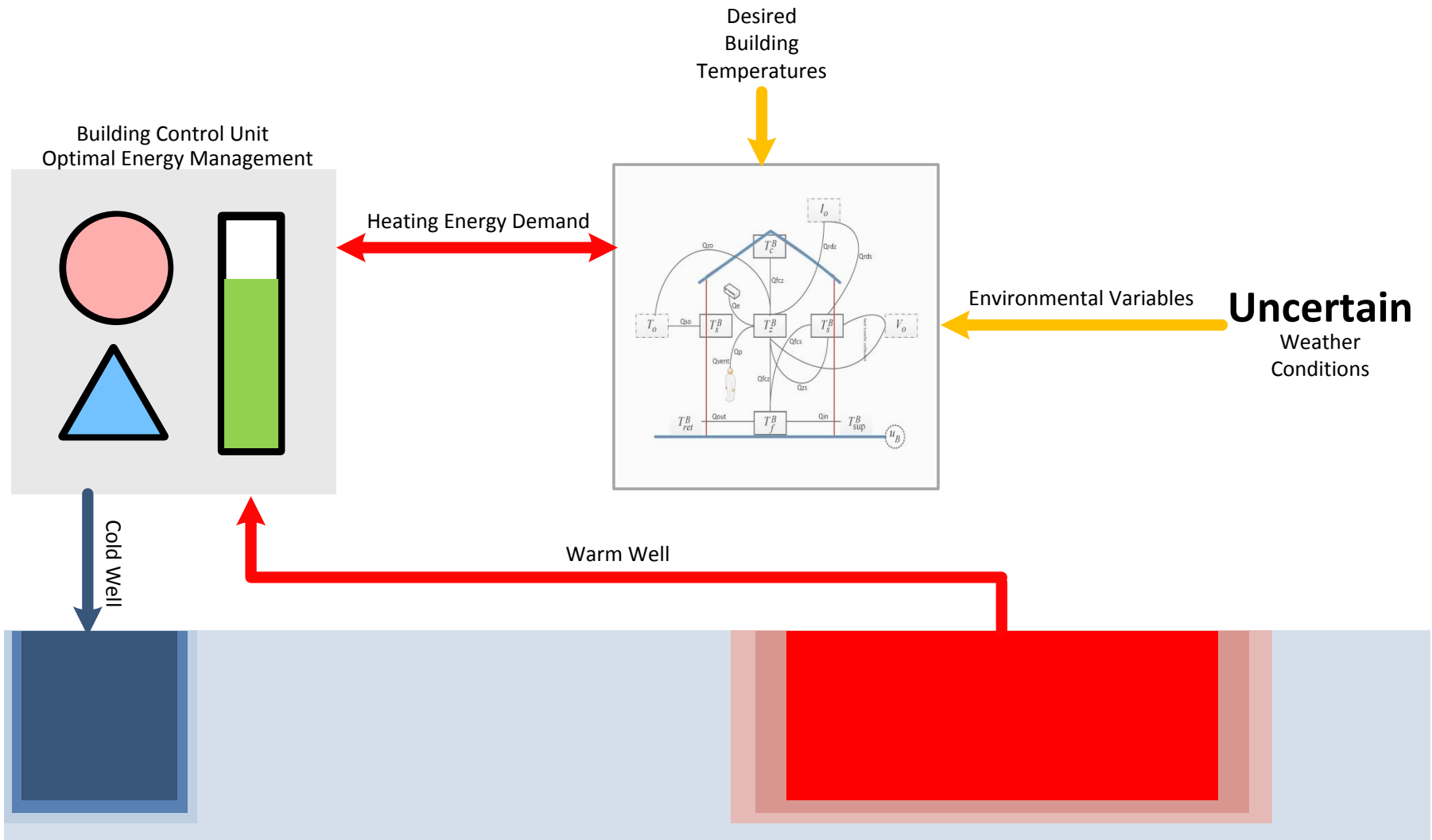

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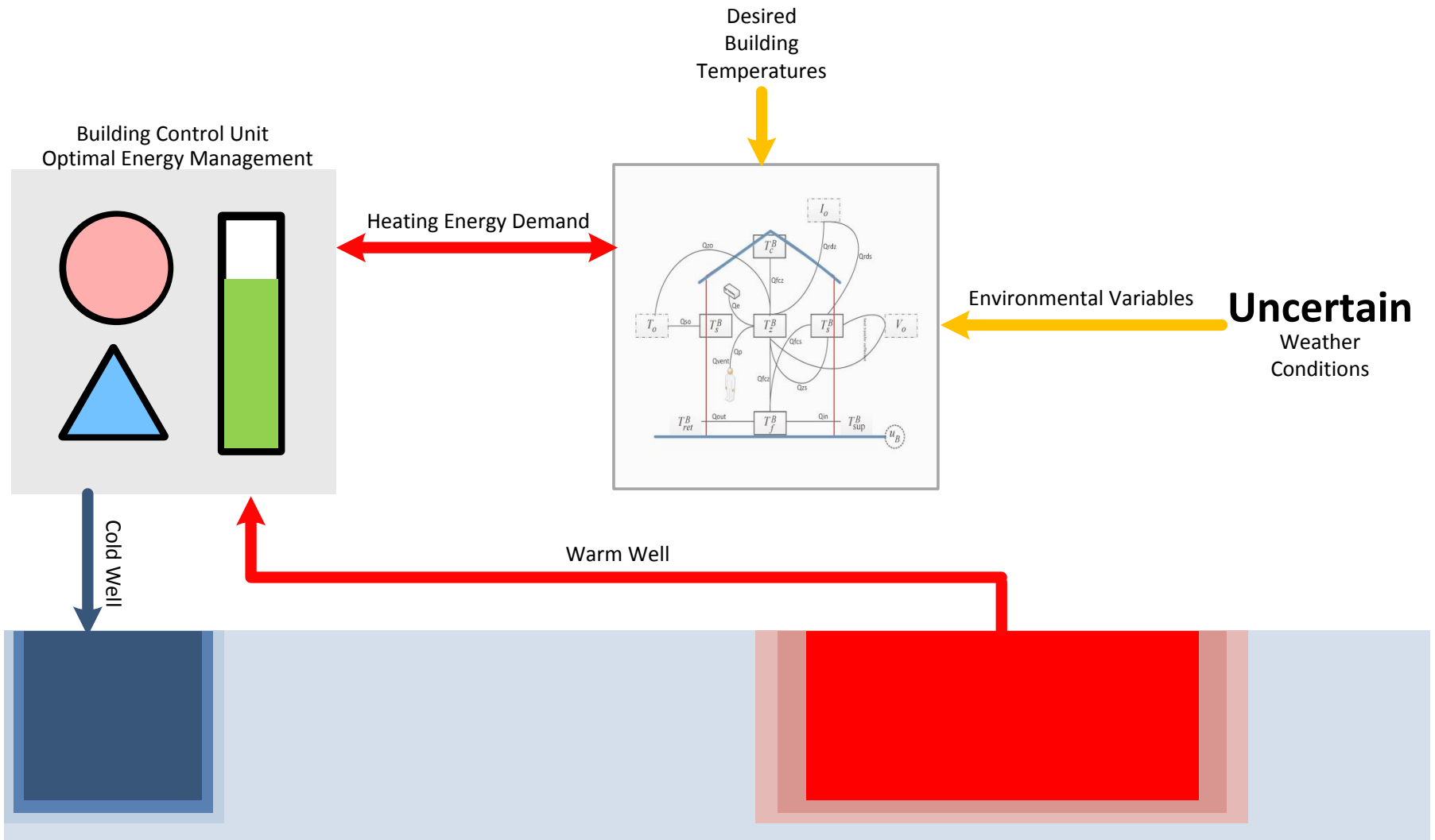

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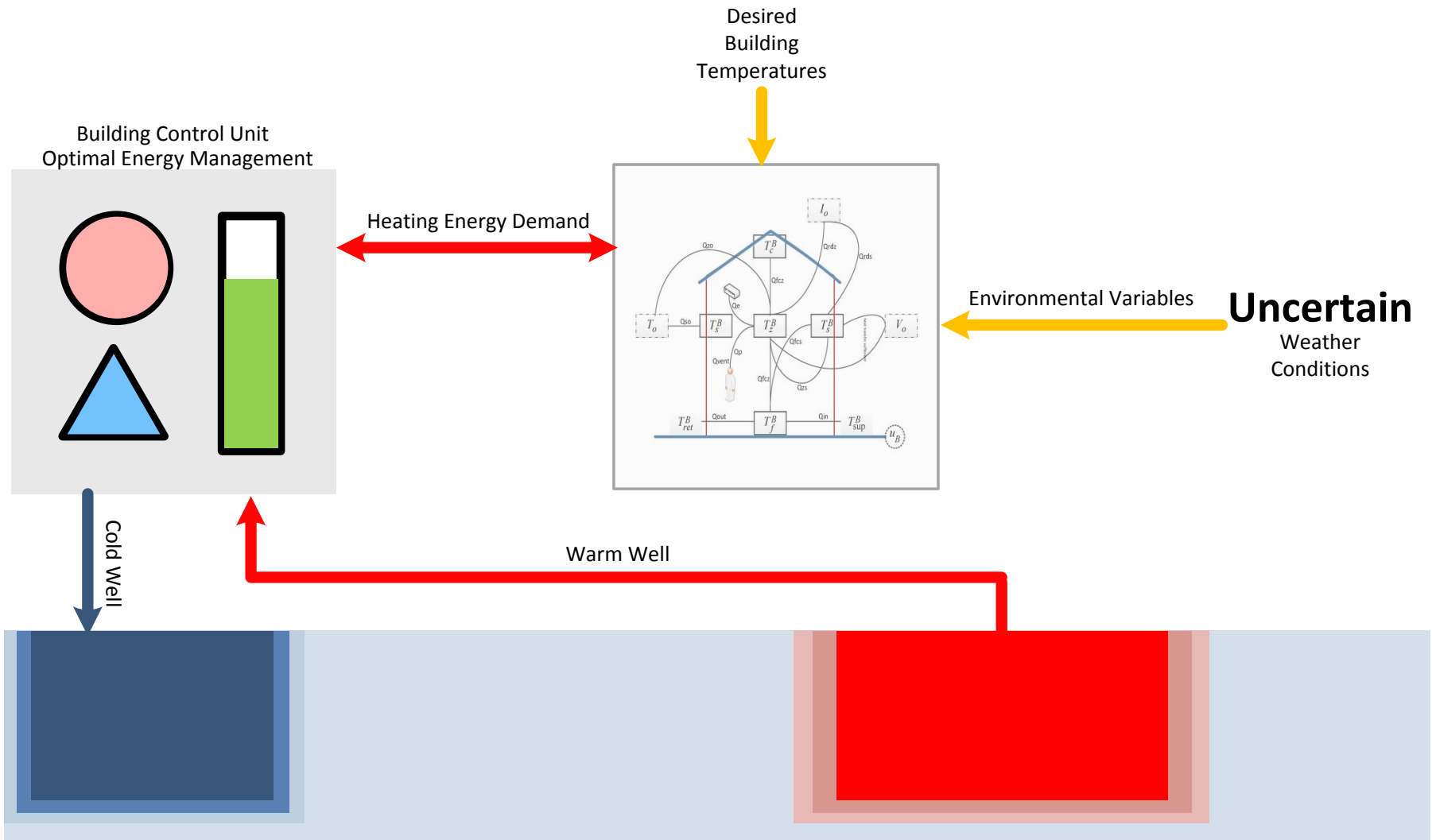

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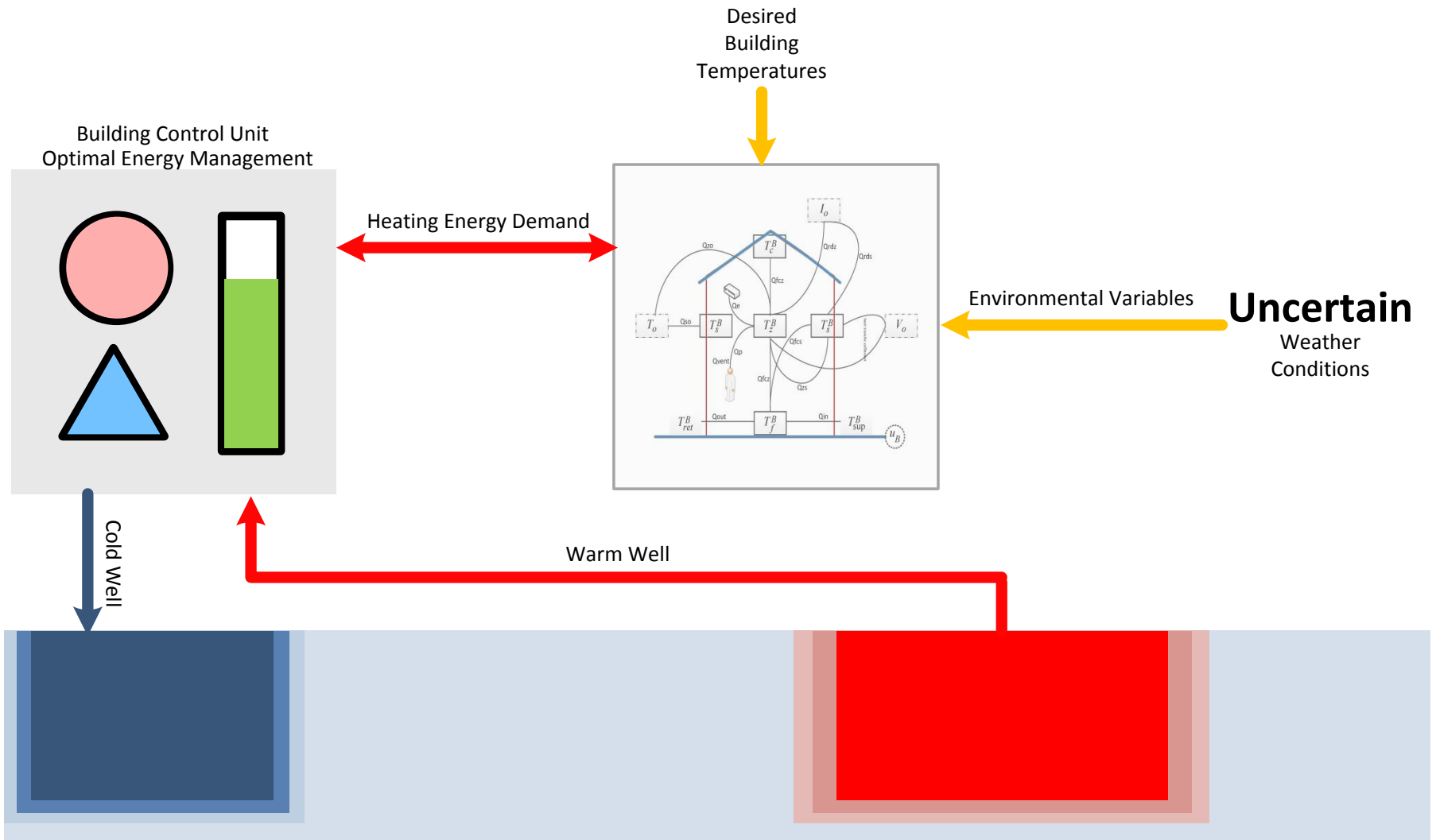

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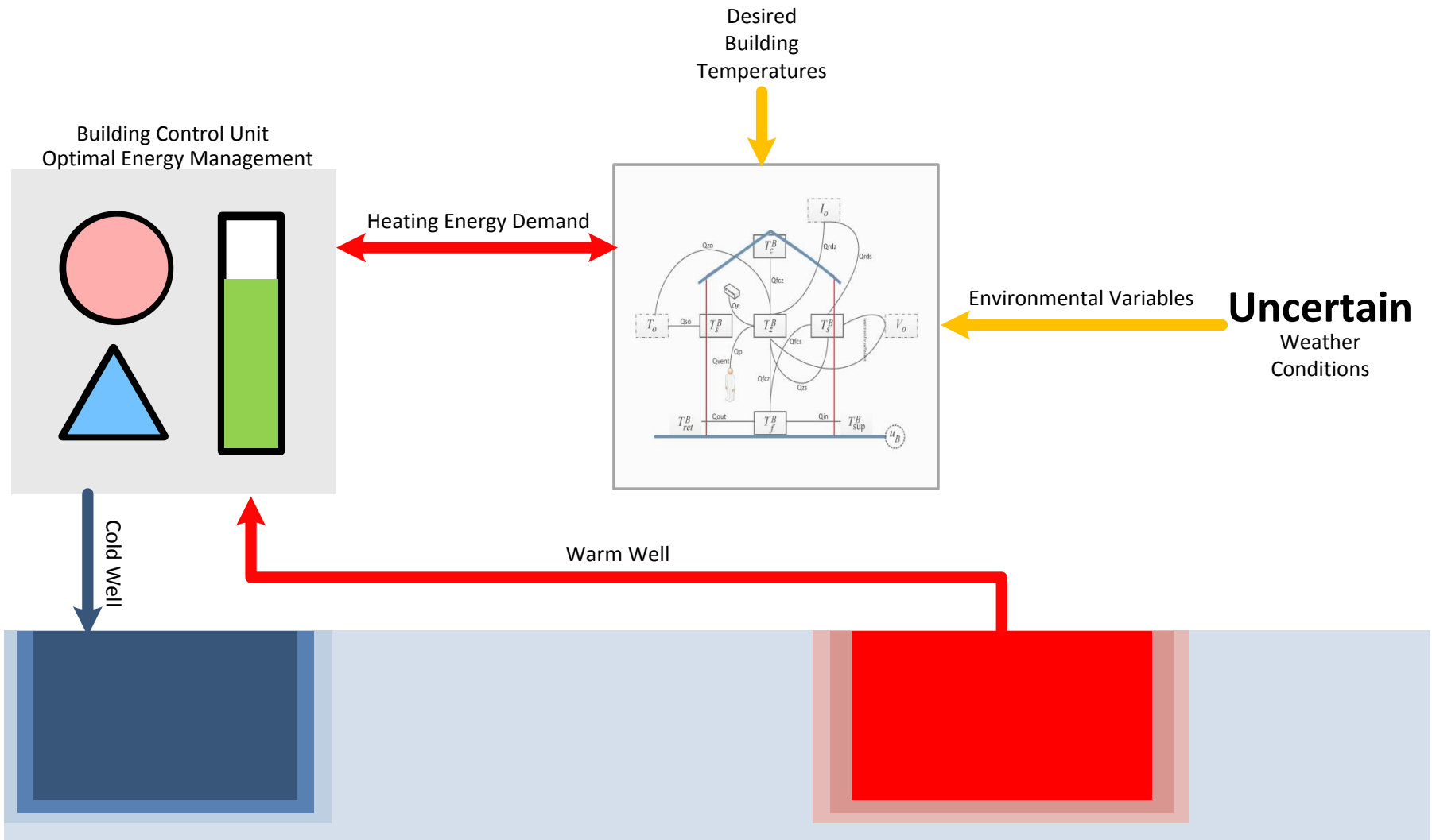

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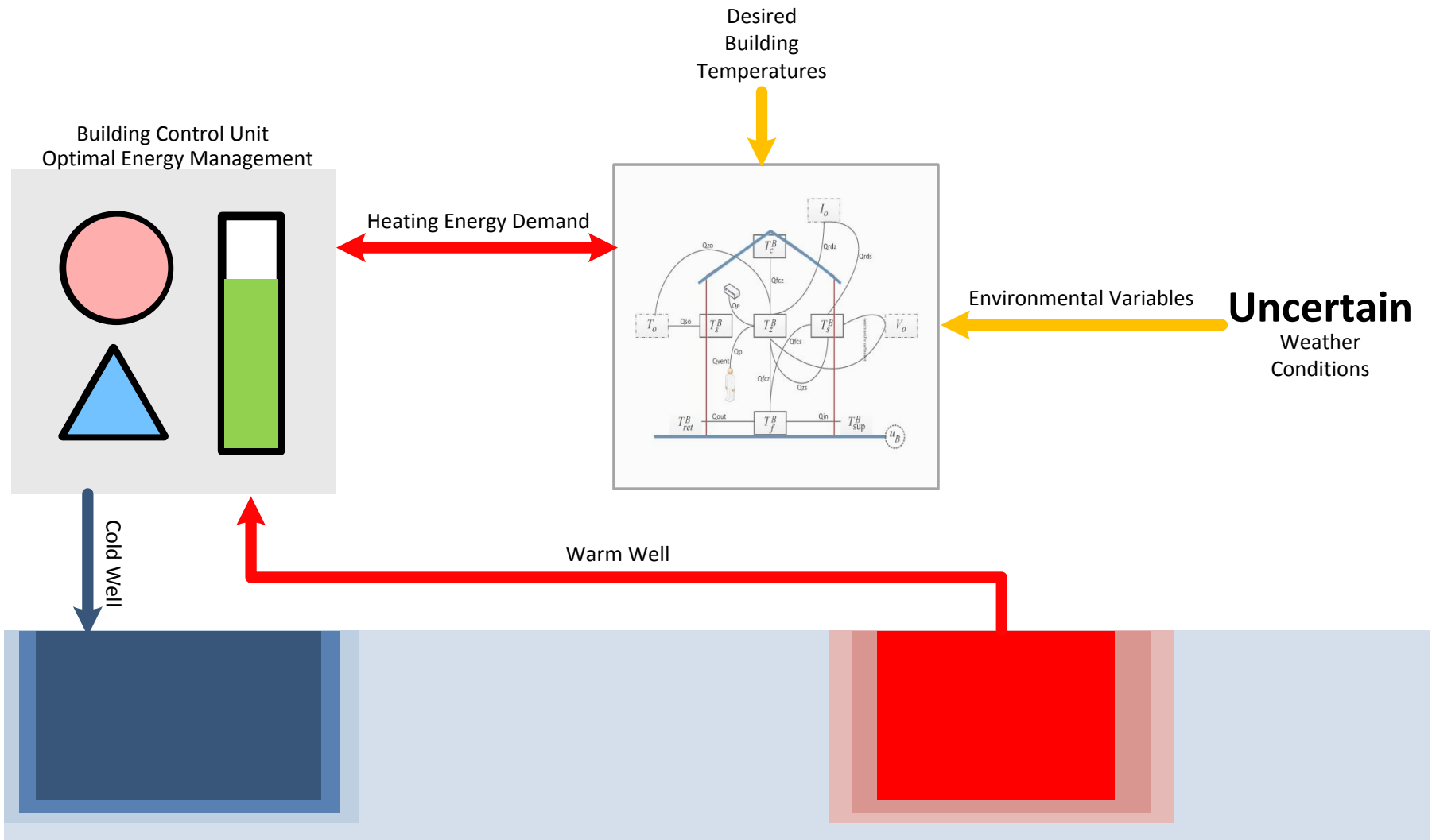

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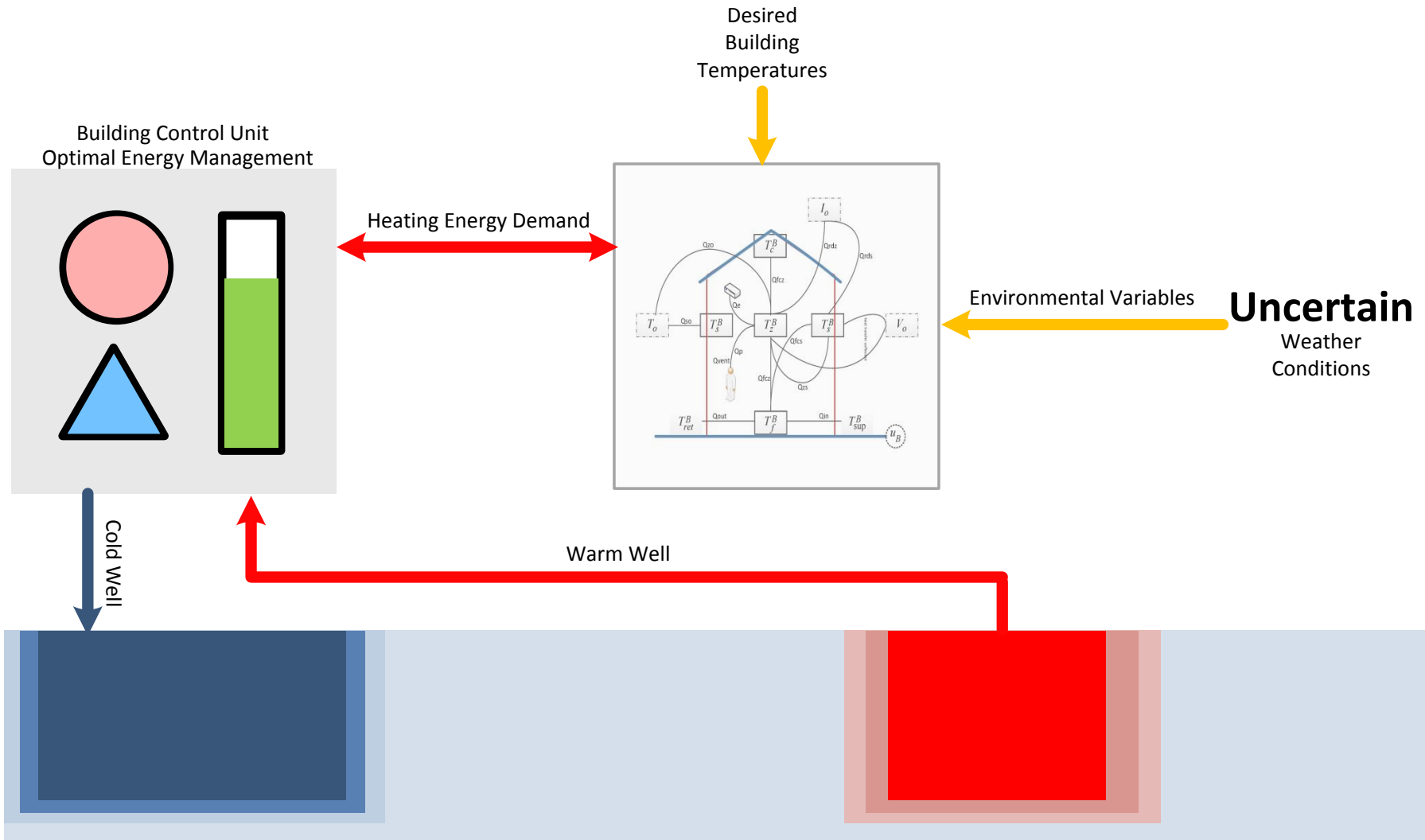

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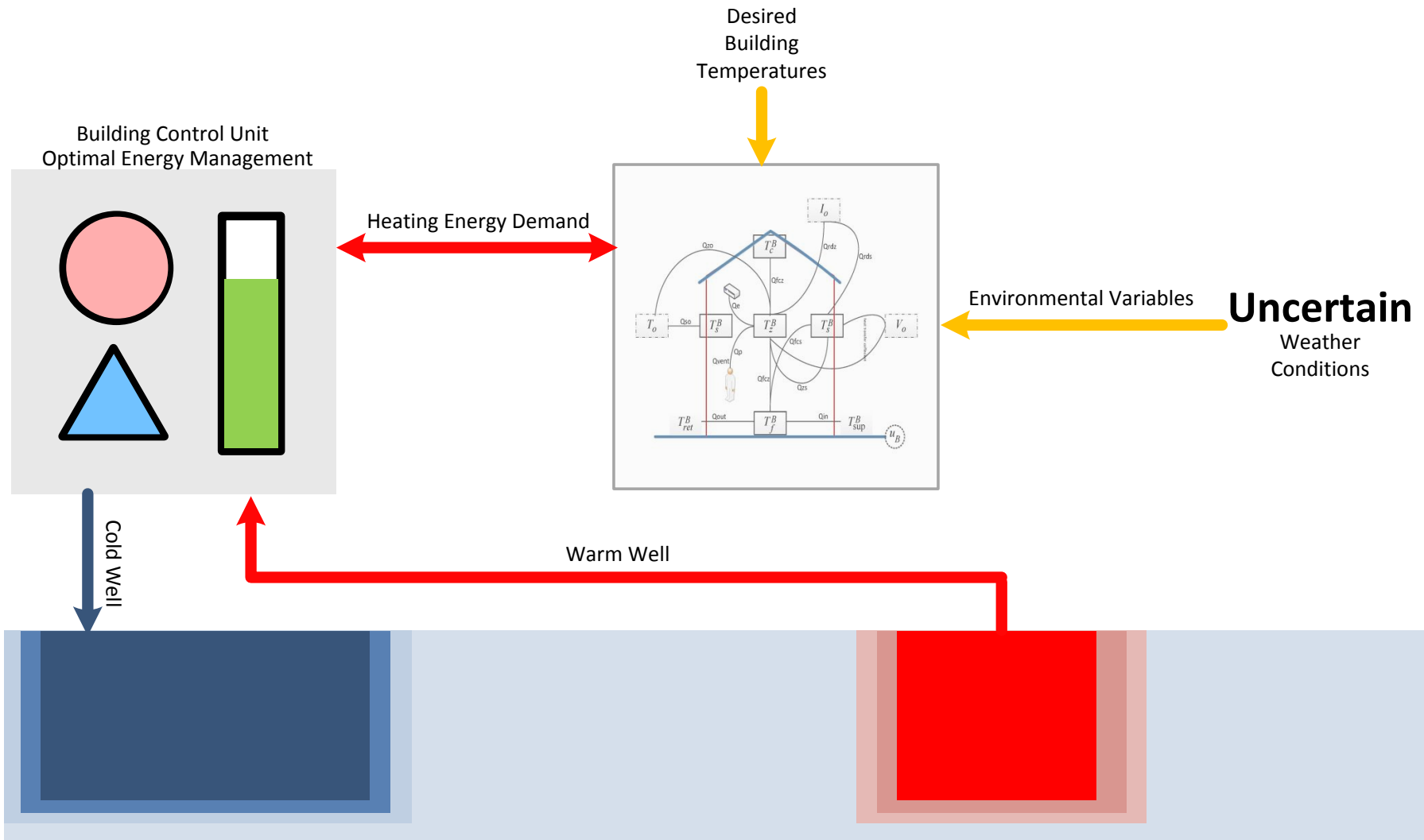

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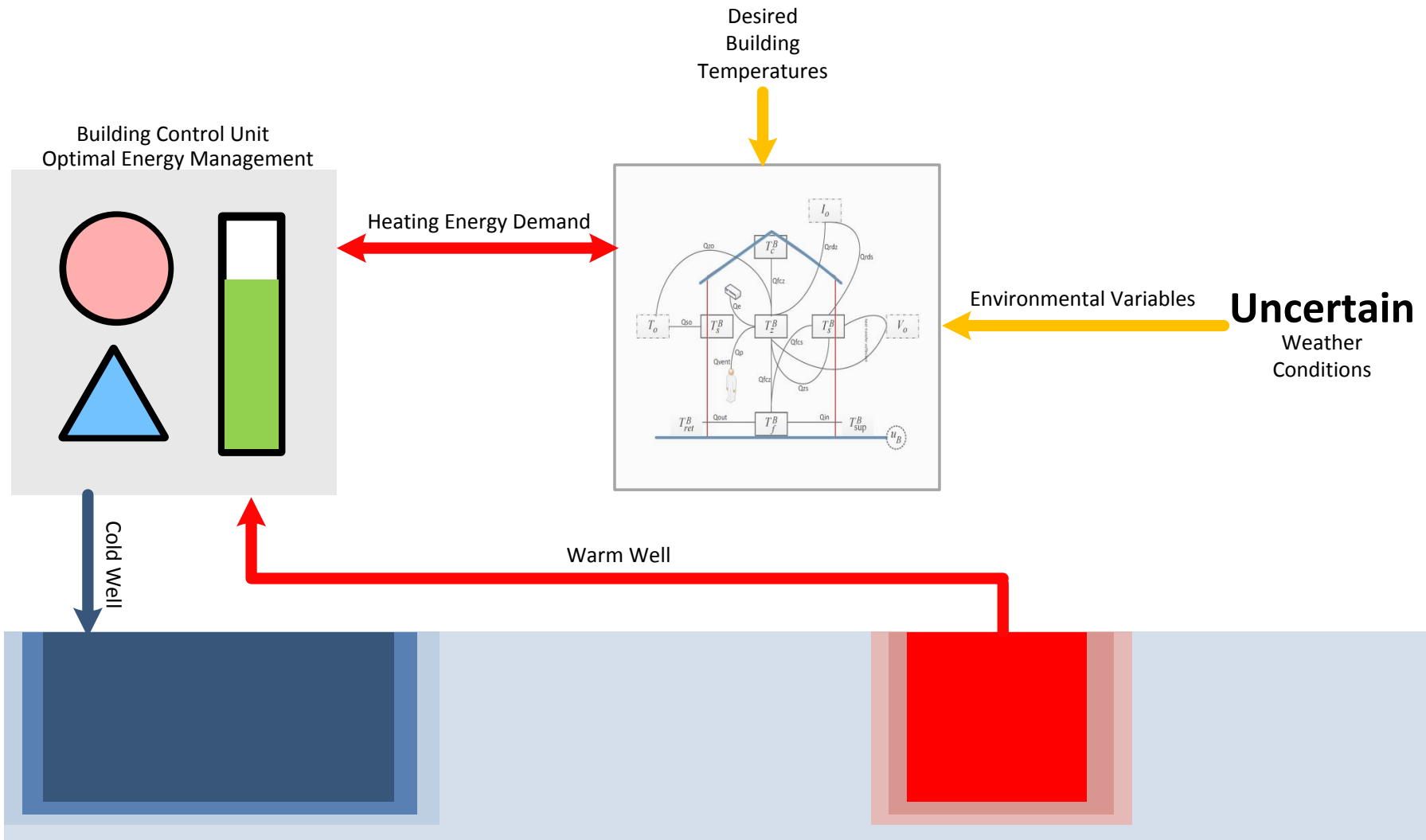

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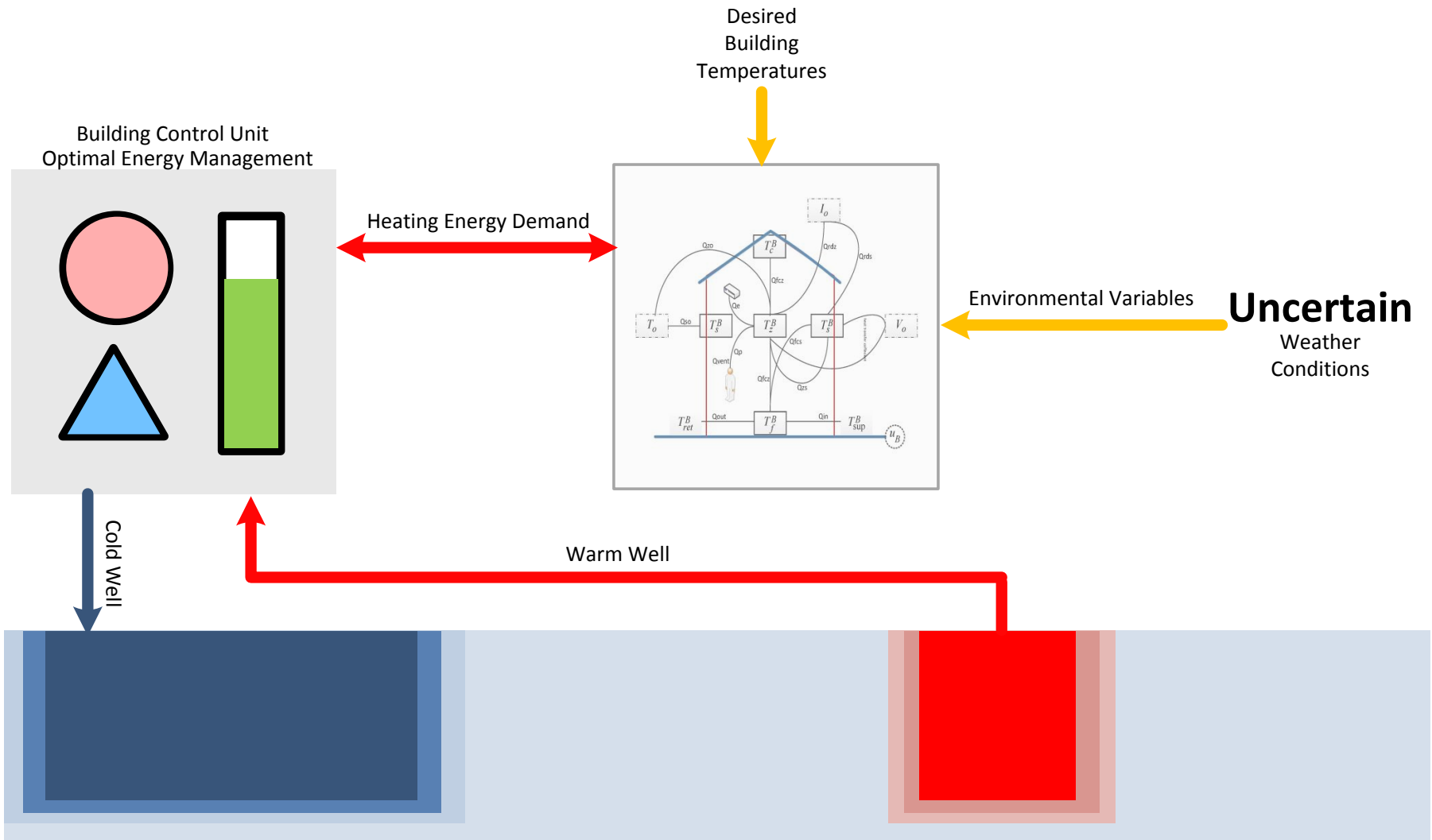

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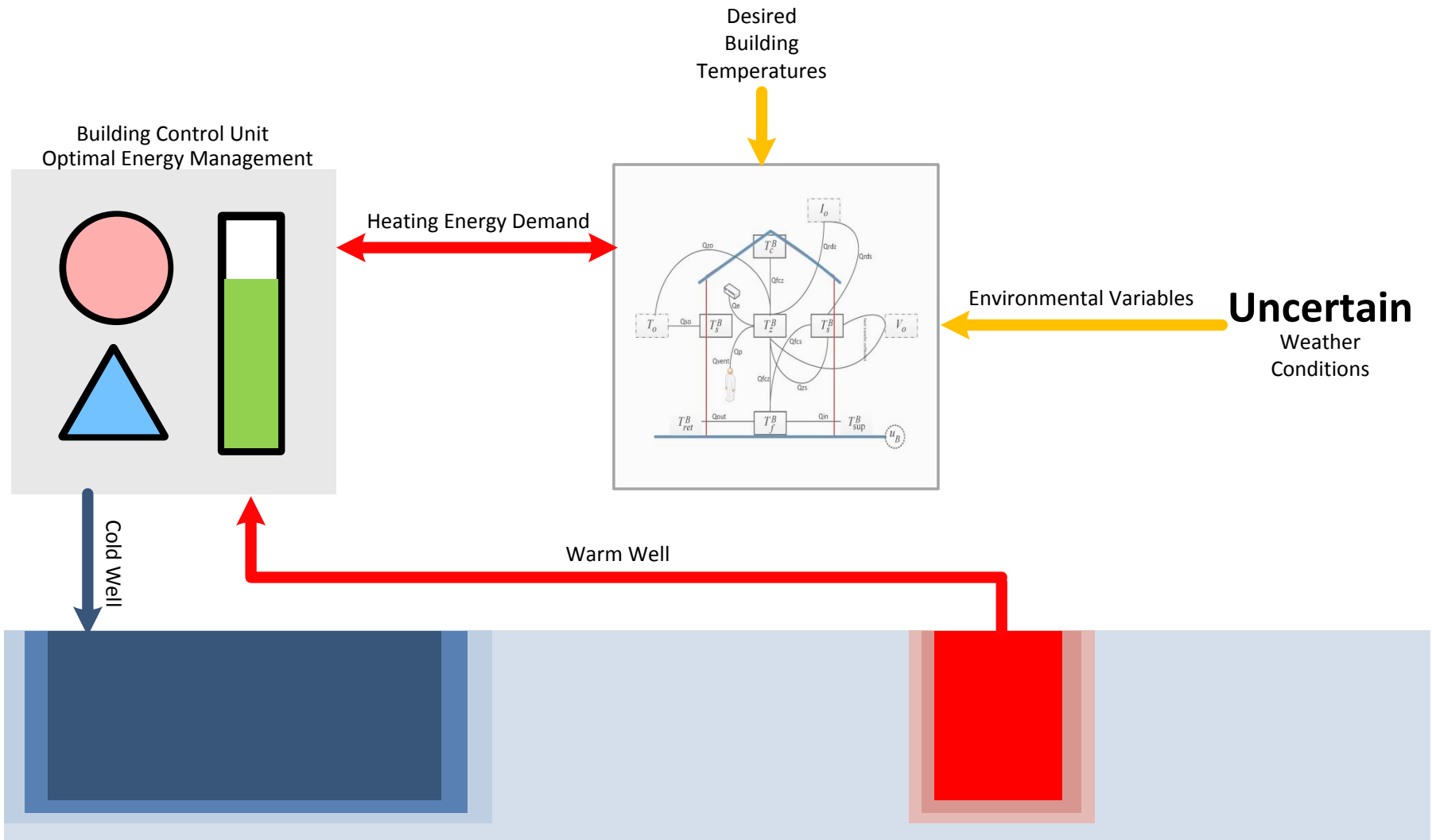

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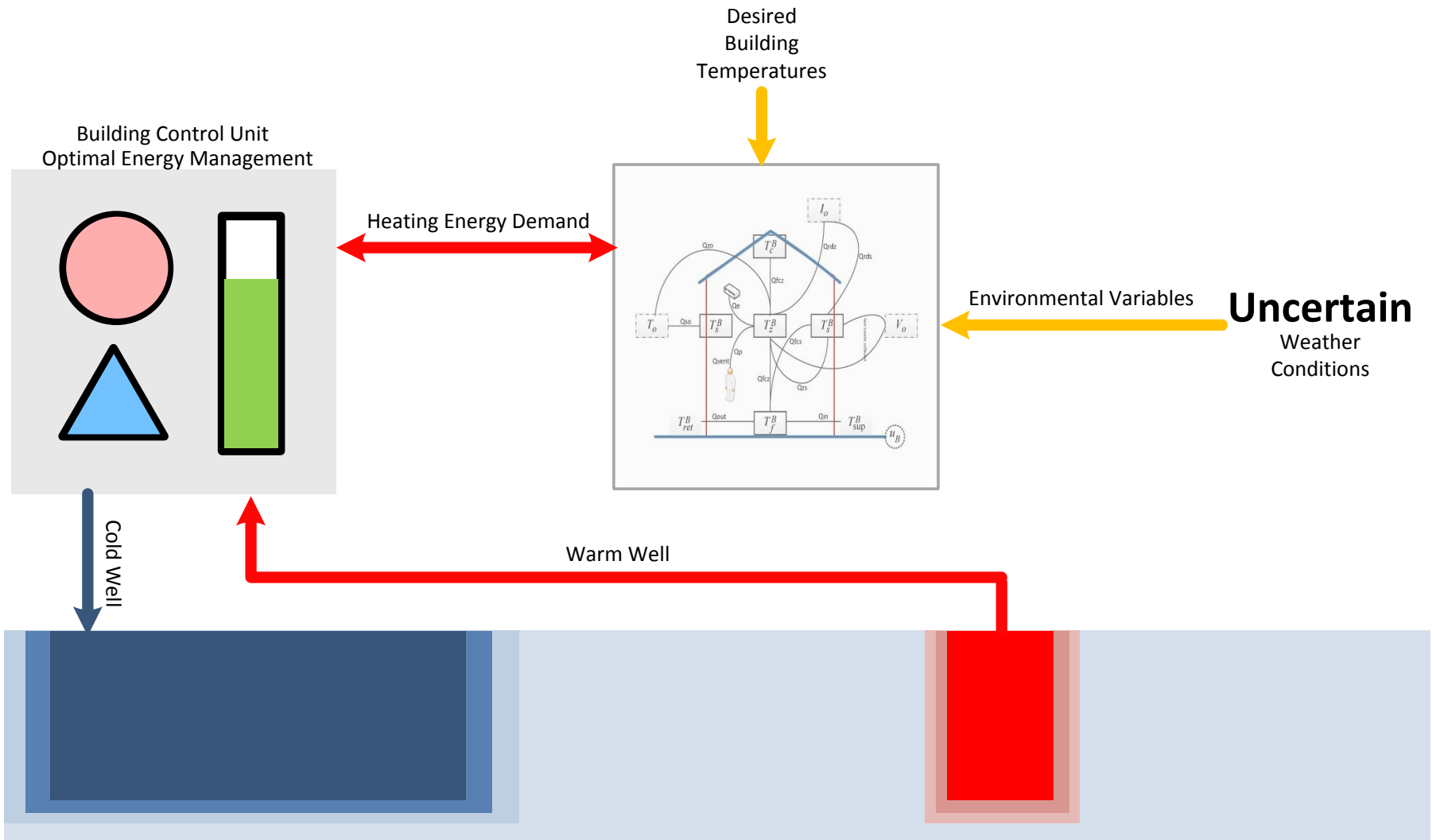
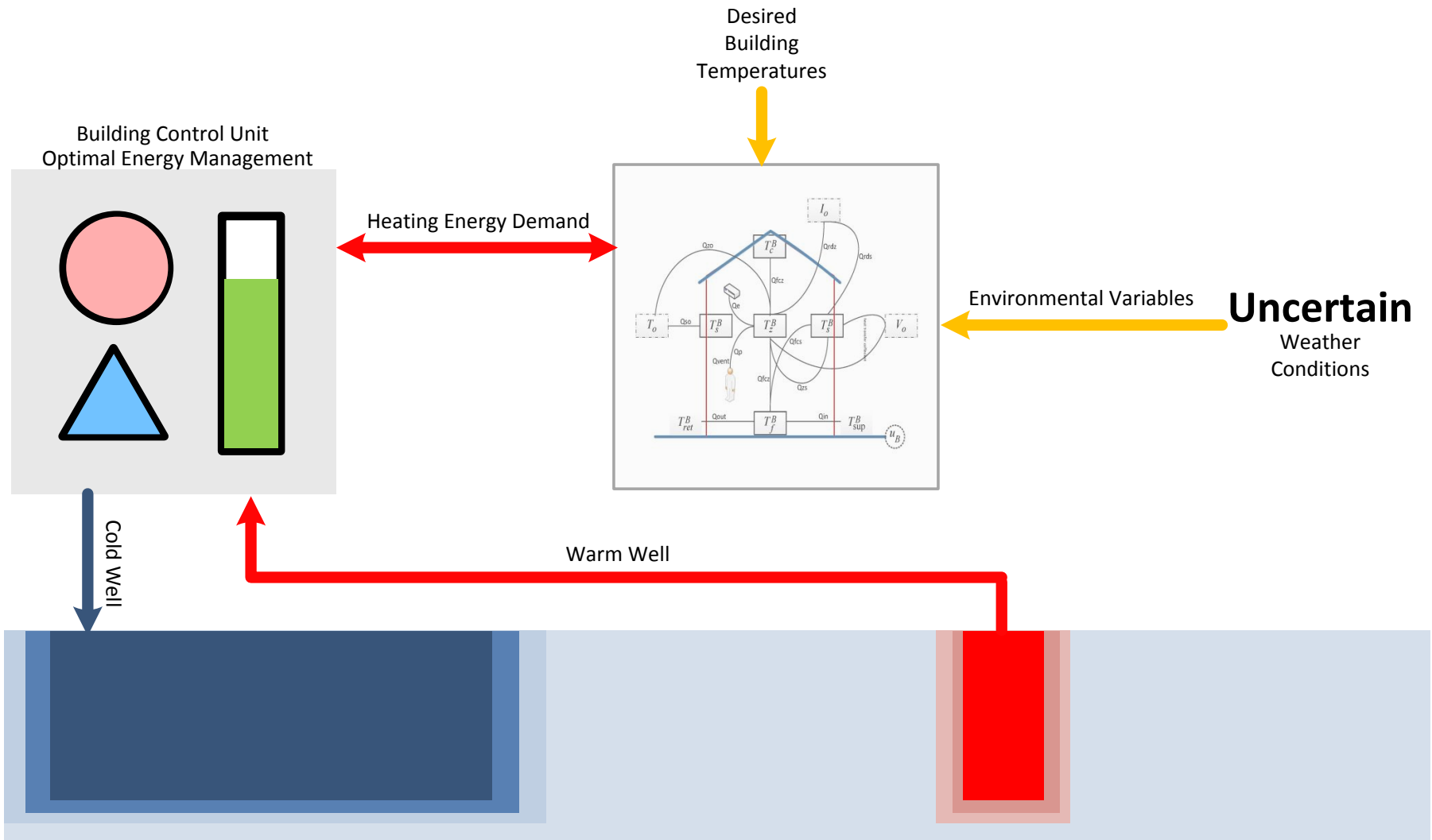


[Rostampour et al., European Geosciences Union 2017]

Model Predictive Dynamics: Heating Mode



[Rostampour et al., European Geosciences Union 2017]

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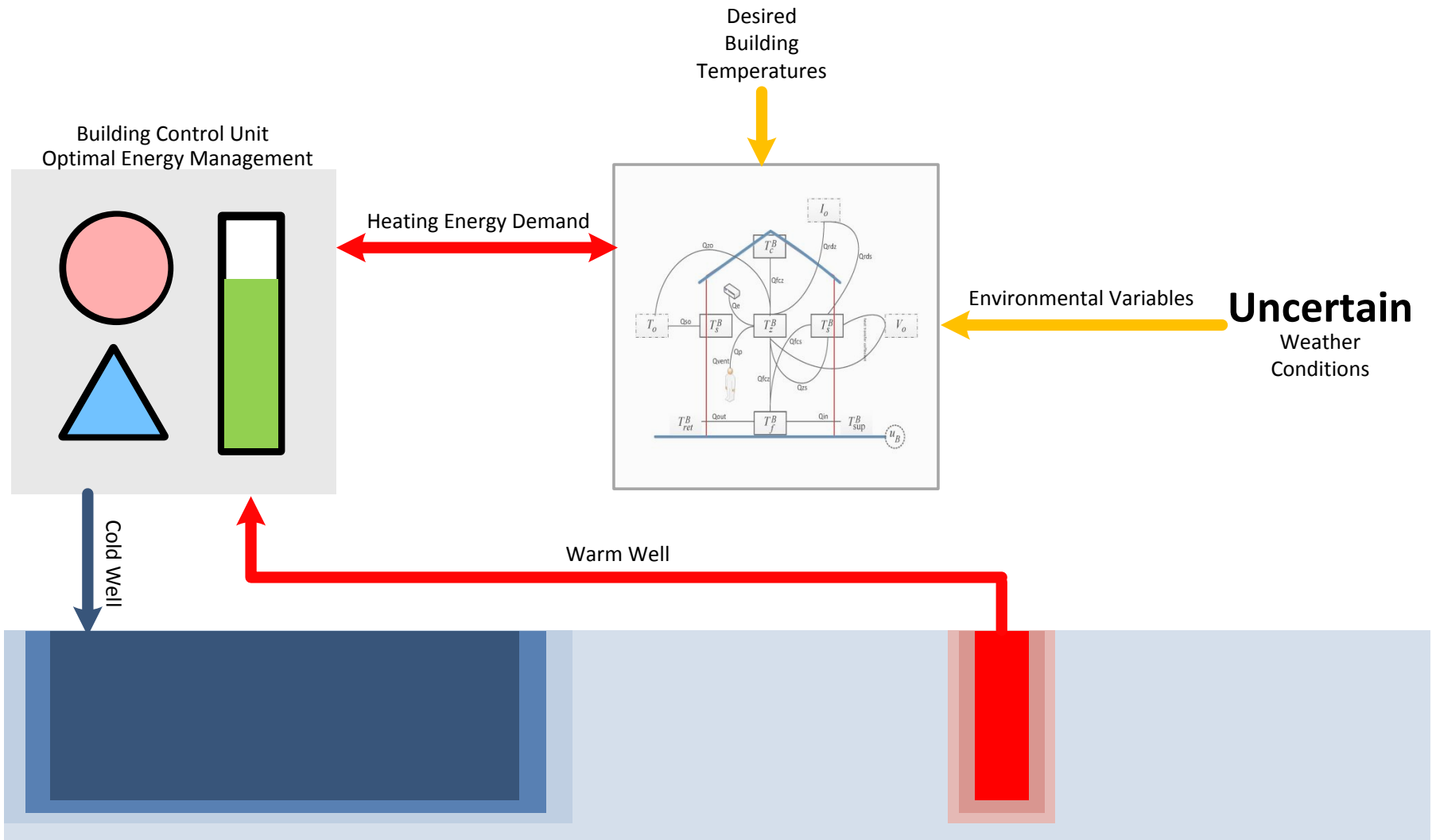

[Rostampour et al., European Geosciences Union 2017]

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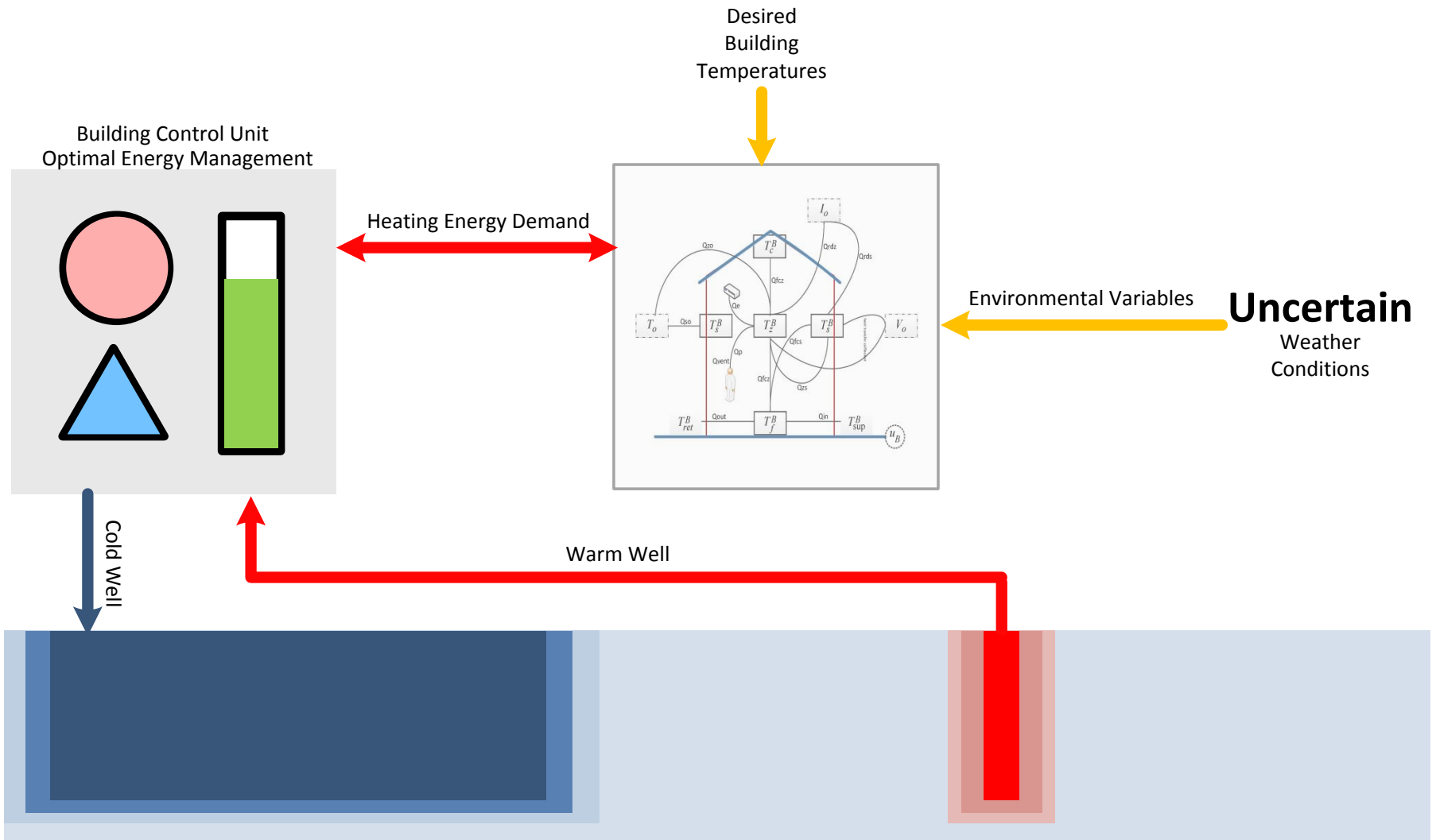

[Rostampour et al., European Geosciences Union 2017]

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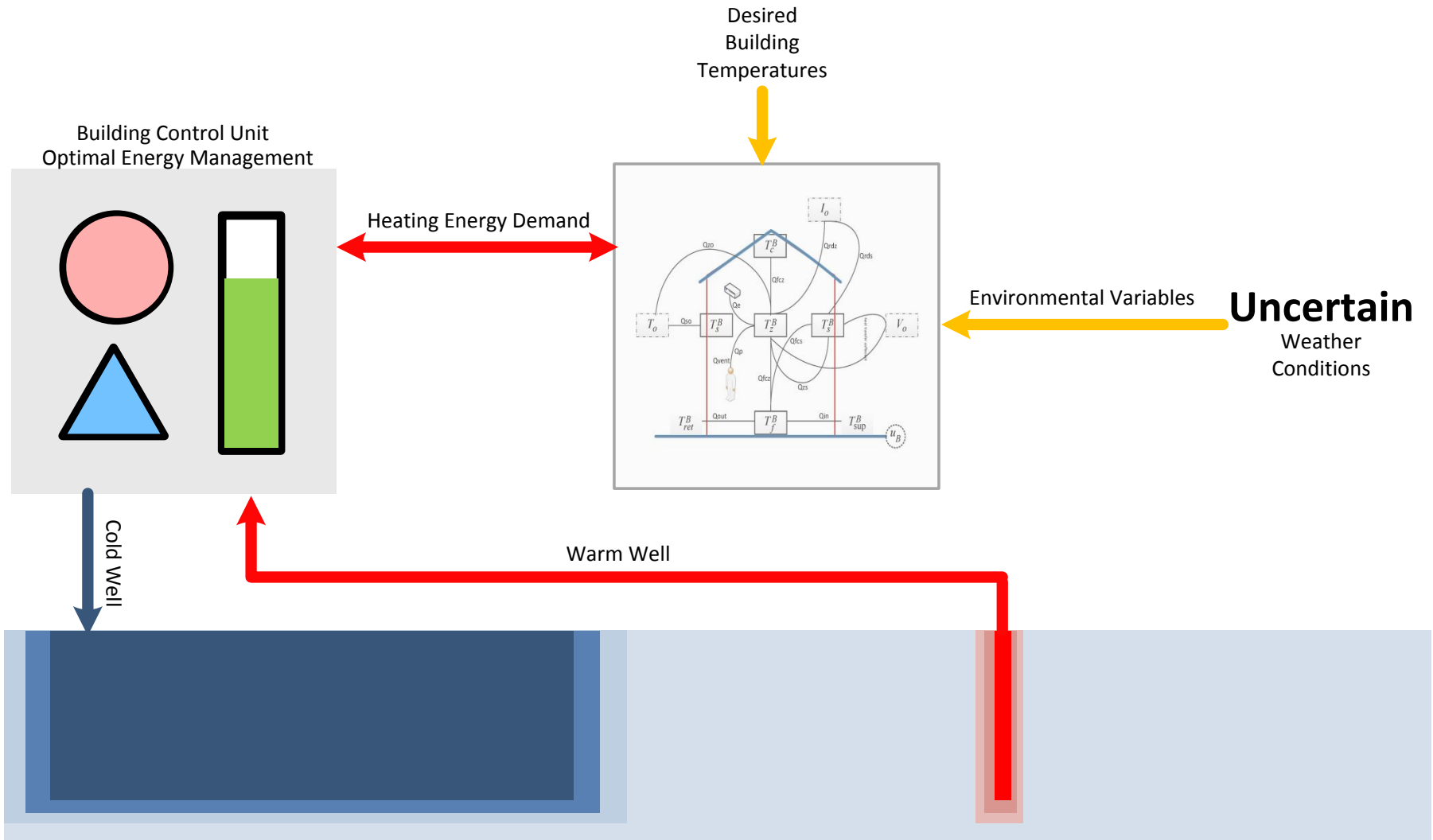
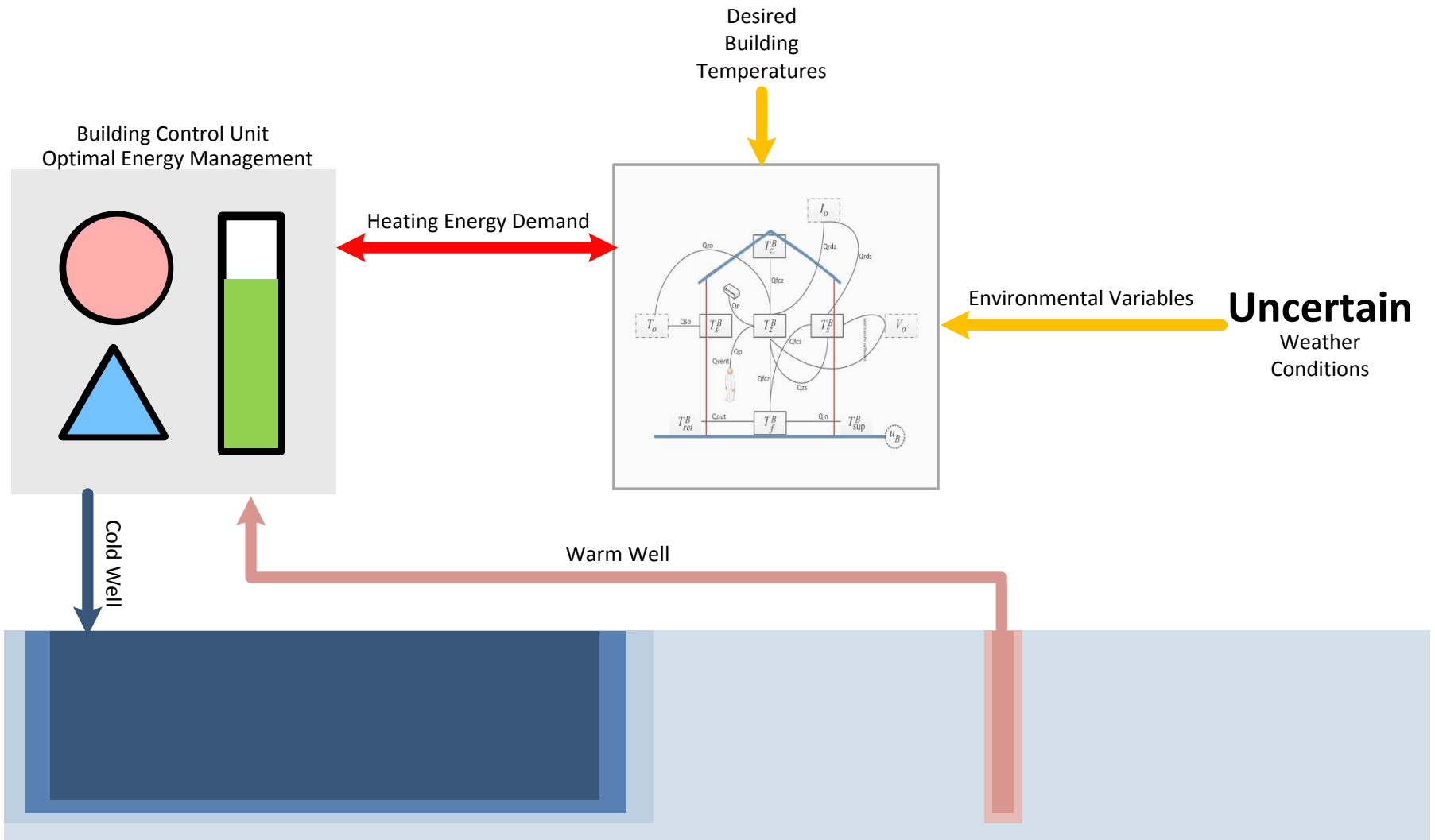


[Rostampour et al., European Geosciences Union 2017]

Proposed Practical Predictive Dynamics: Heating Mode



[Rostampour et al., European Geosciences Union 2017]

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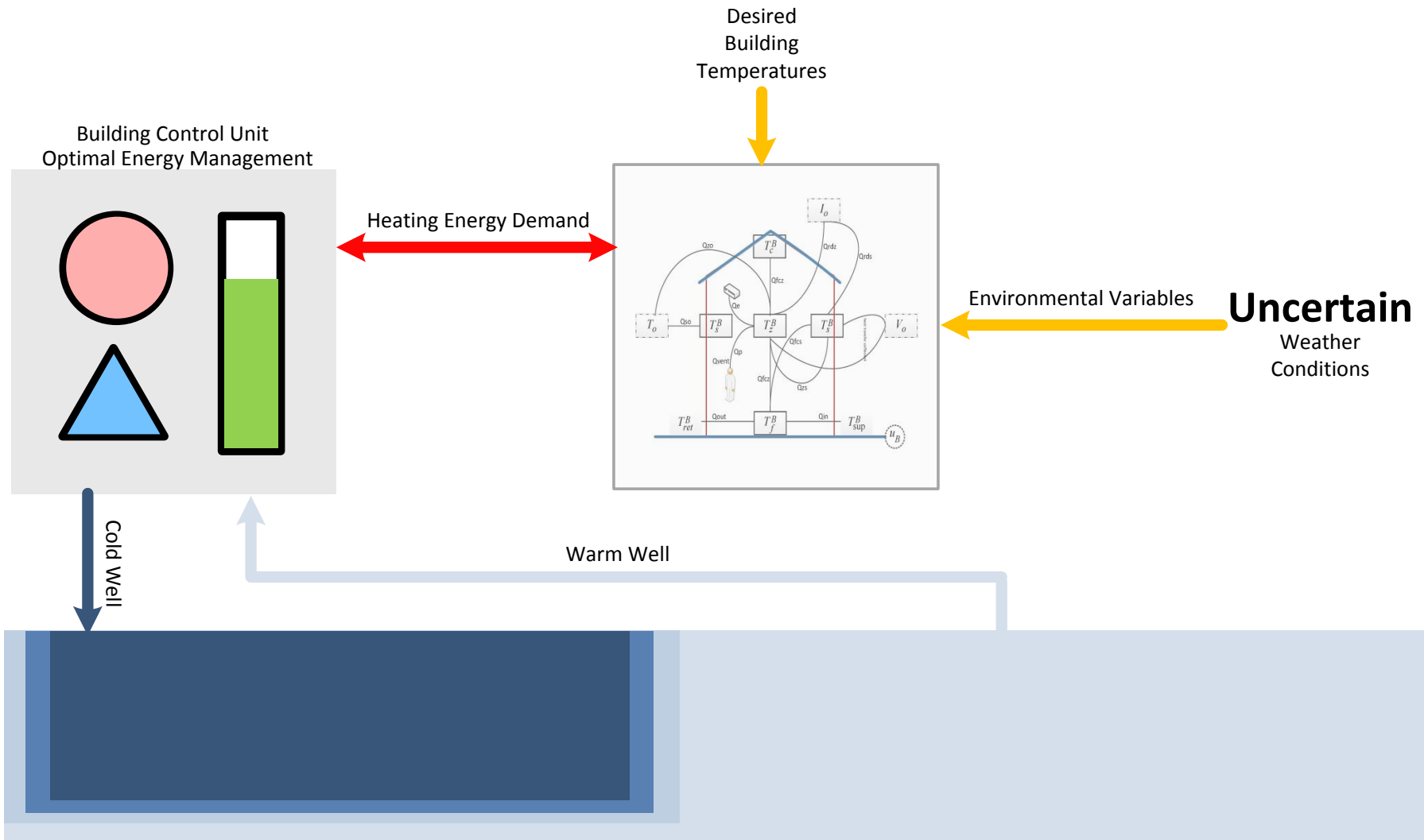

[Rostampour et al., European Geosciences Union 2017]

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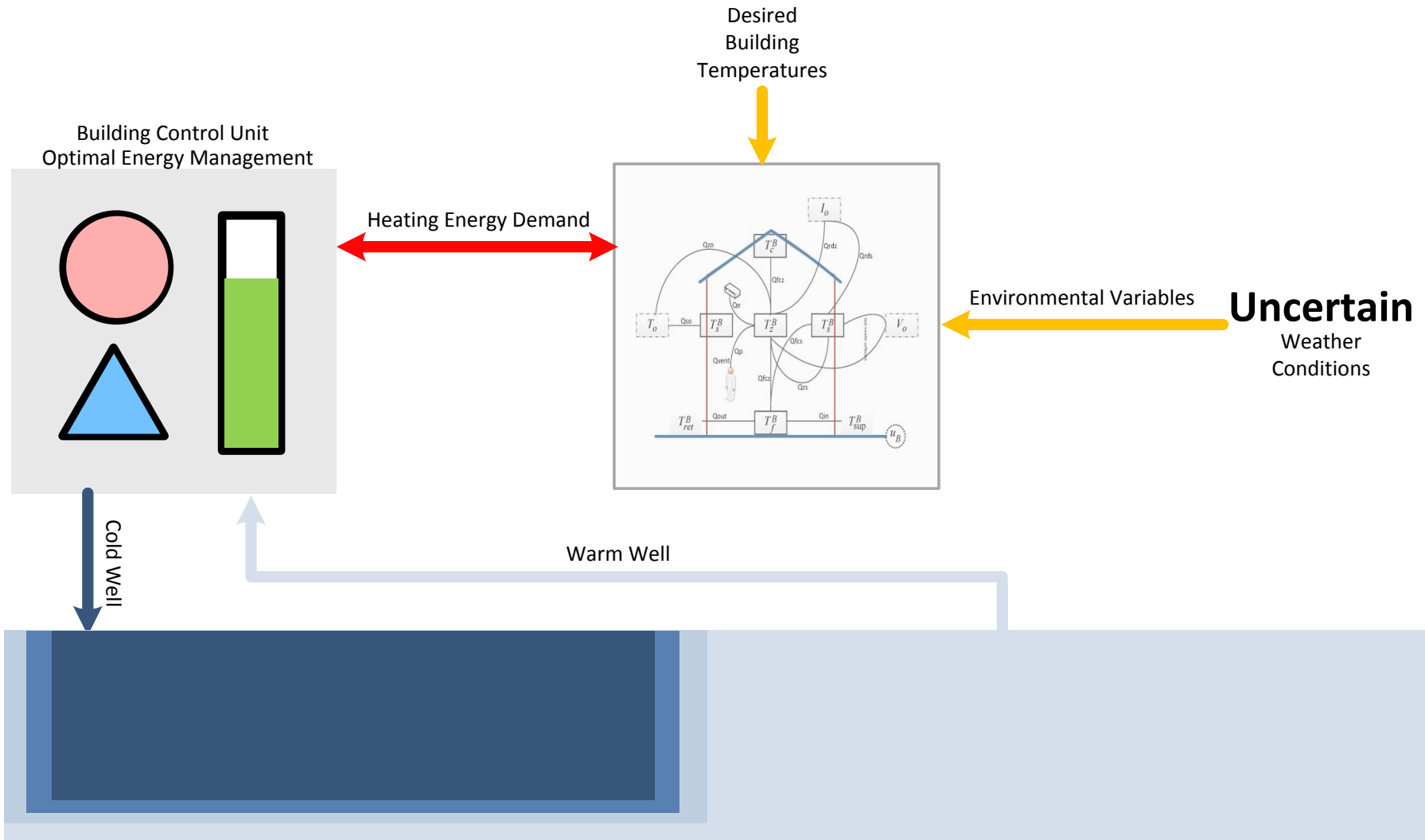

[Rostampour et al., European Geosciences Union 2017]

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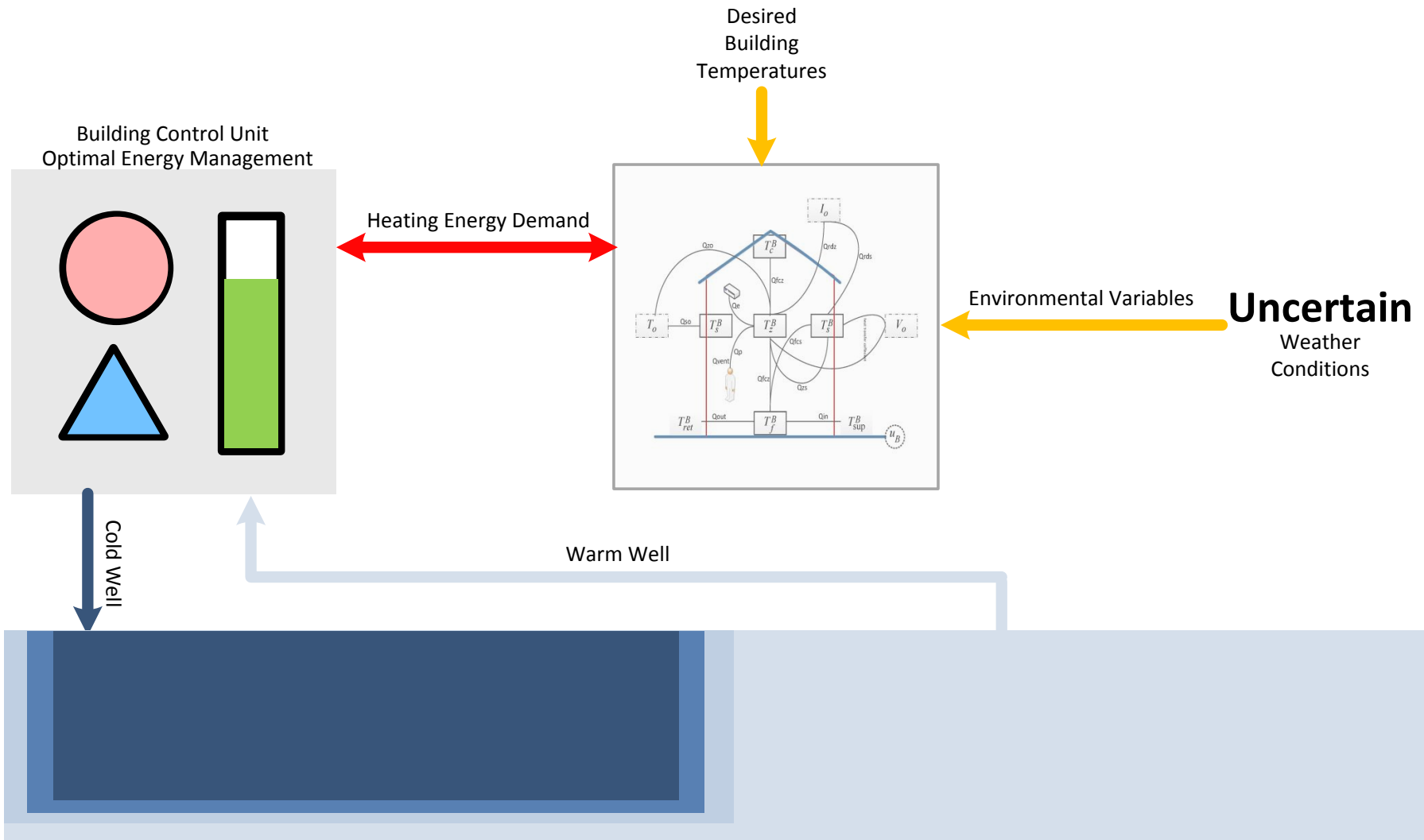

[Rostampour et al., European Geosciences Union 2017]

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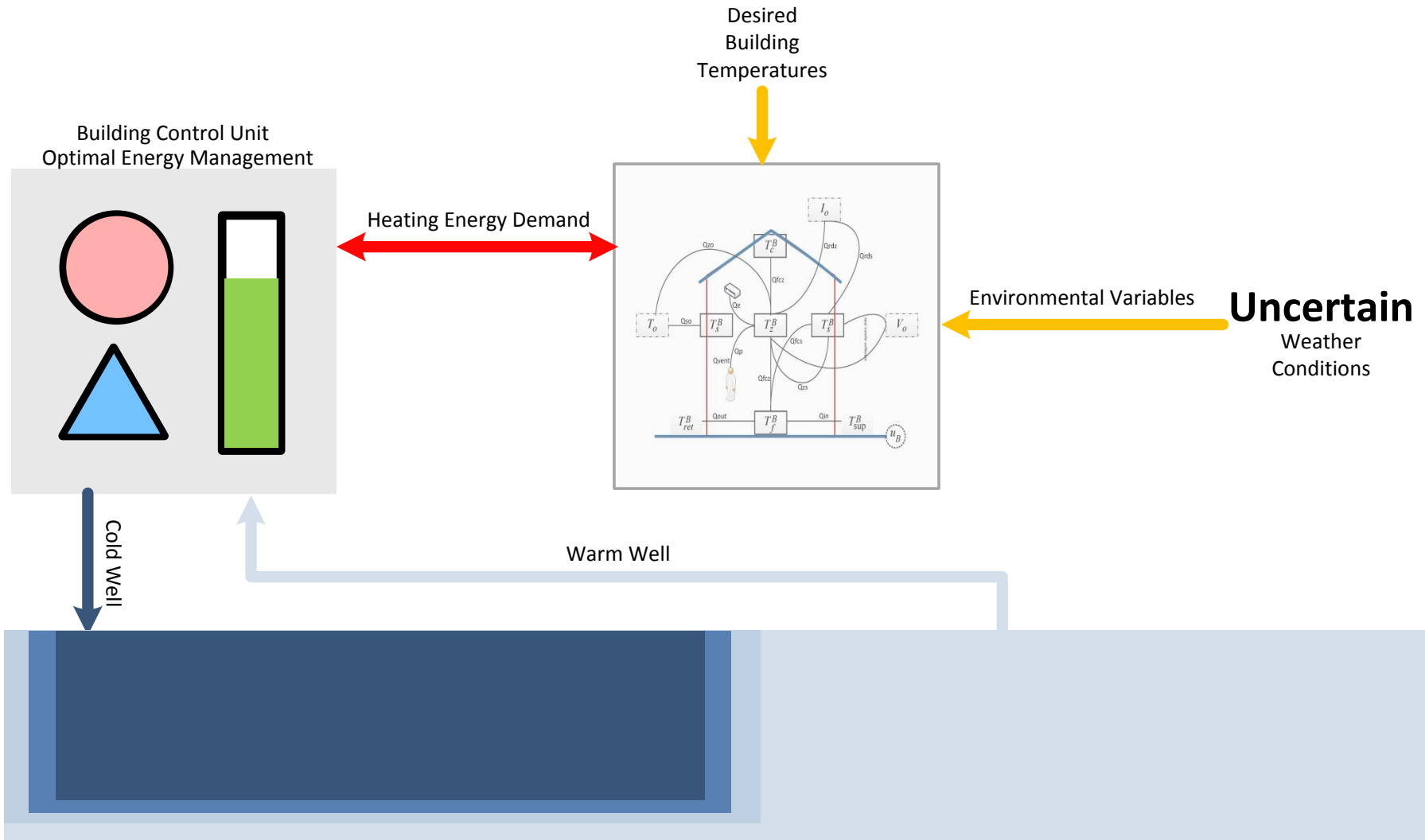

[Rostampour et al., European Geosciences Union 2017]

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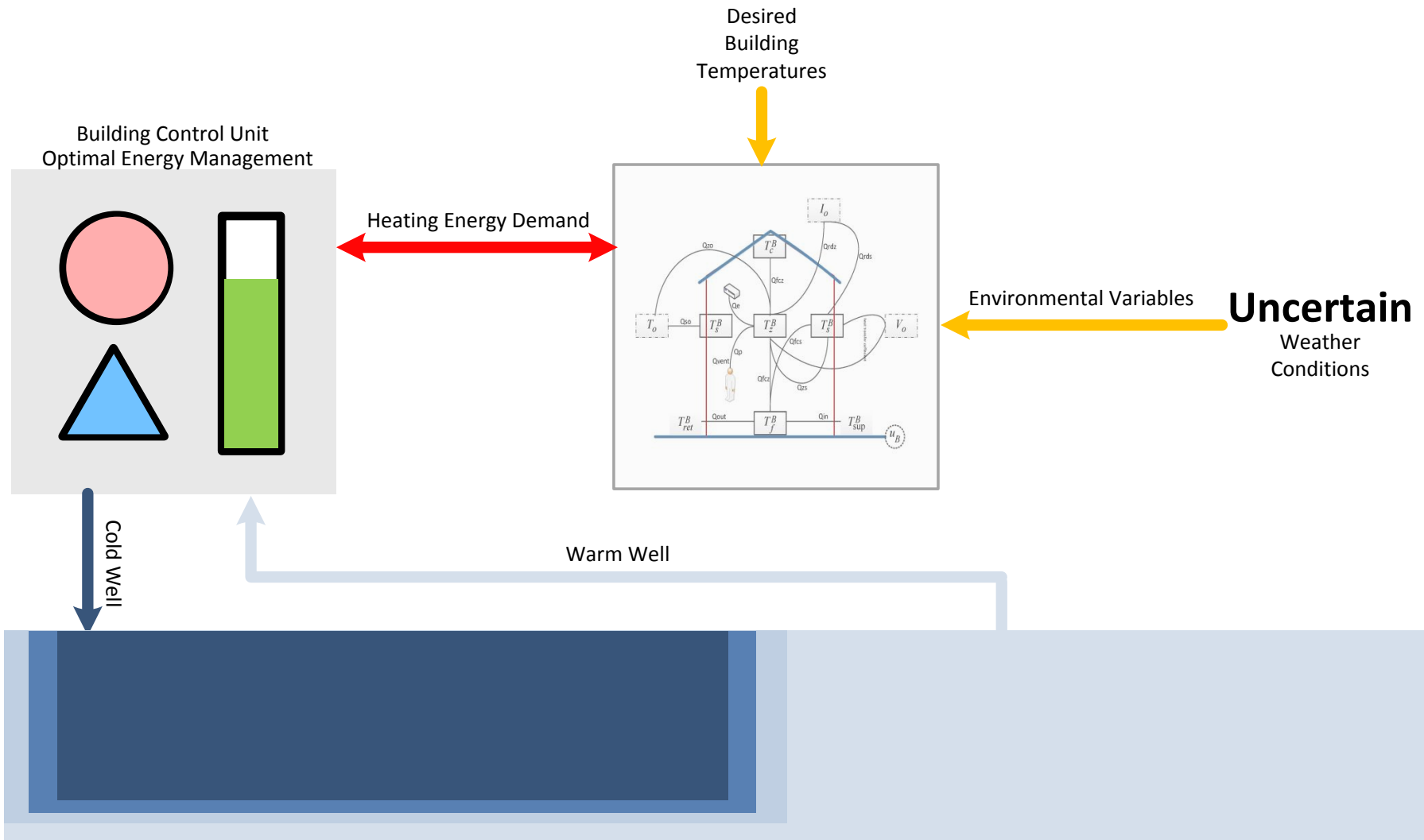

[Rostampour et al., European Geosciences Union 2017]

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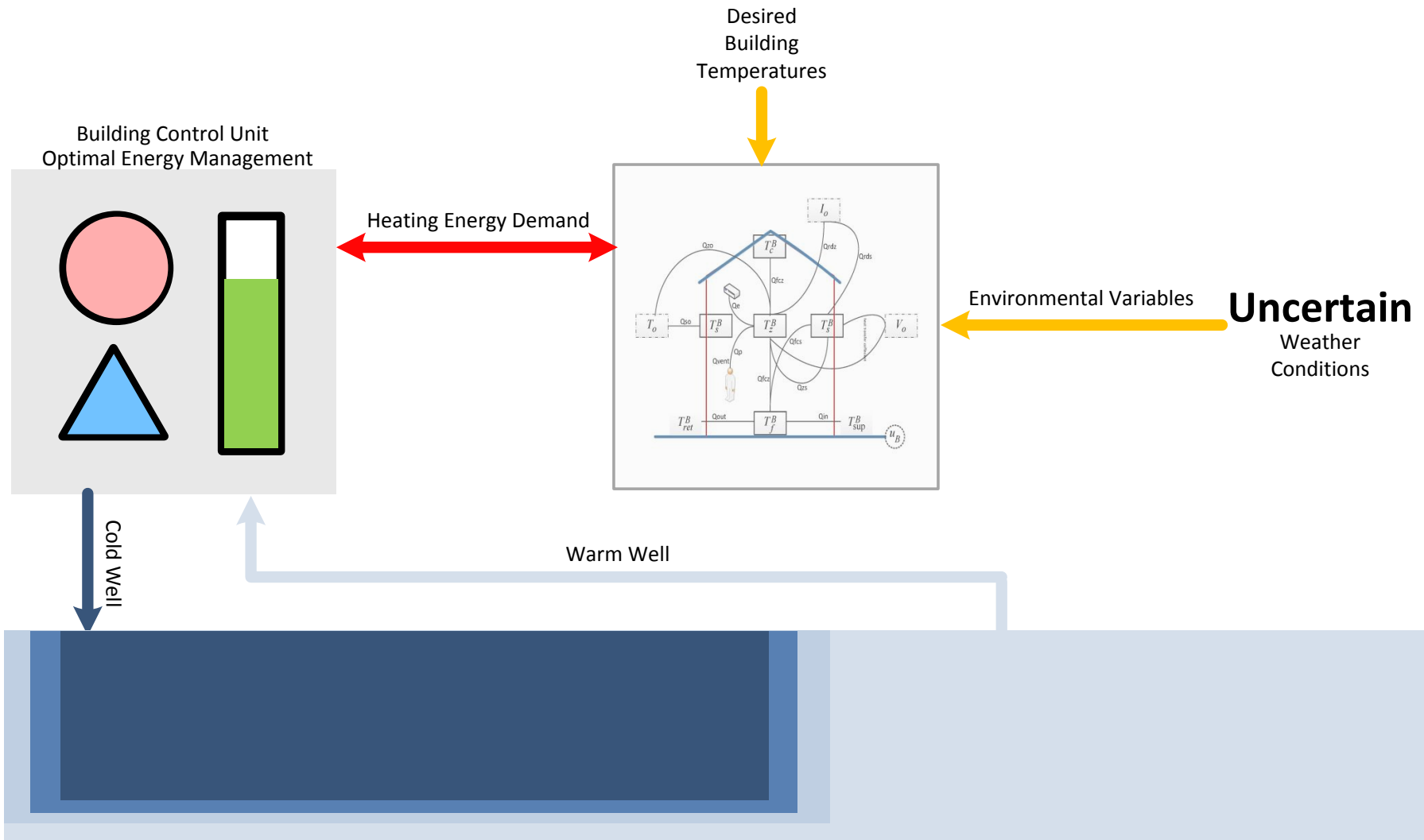
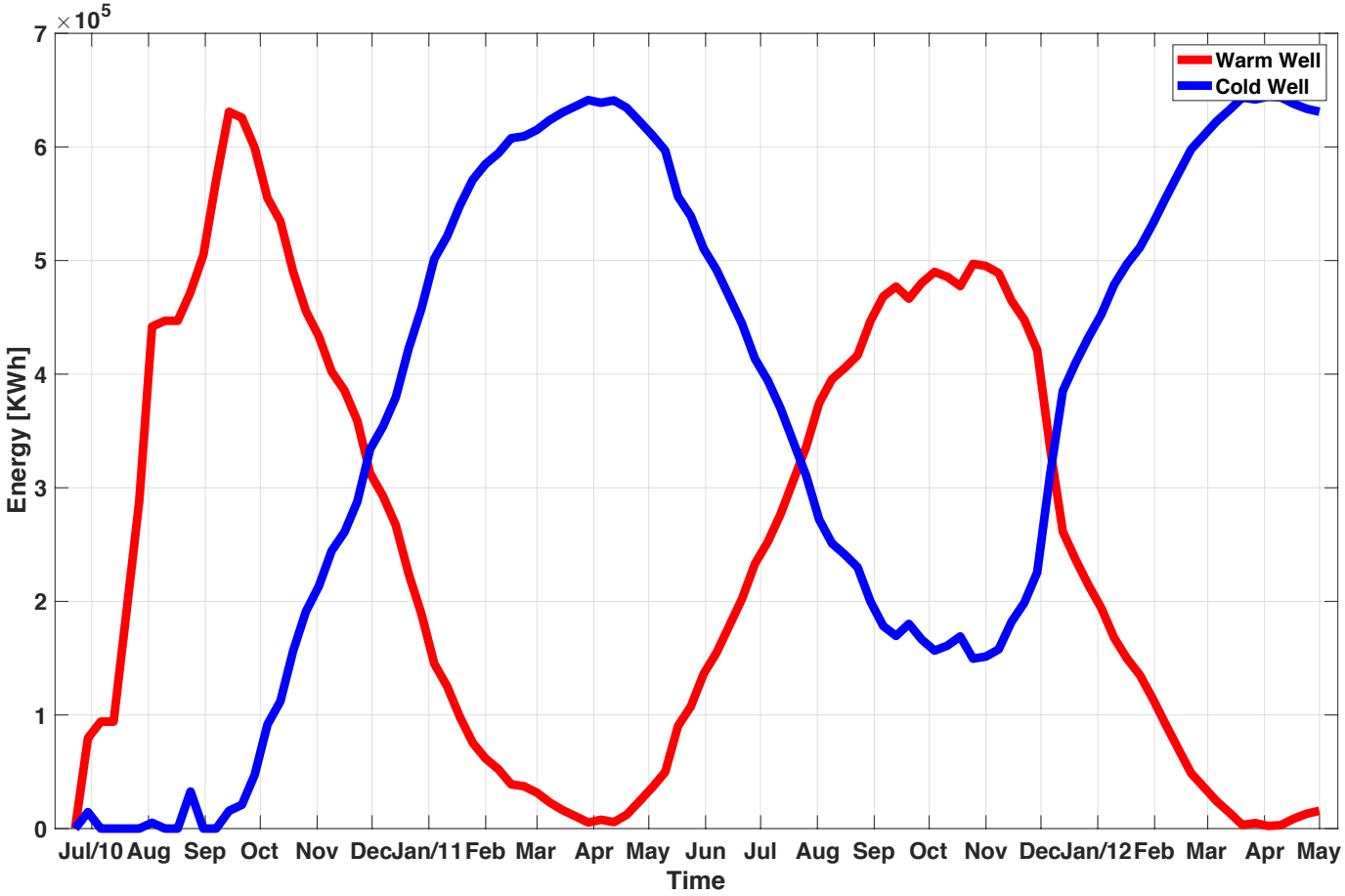


[Rostampour et al., European Geosciences Union 2017]

Outline

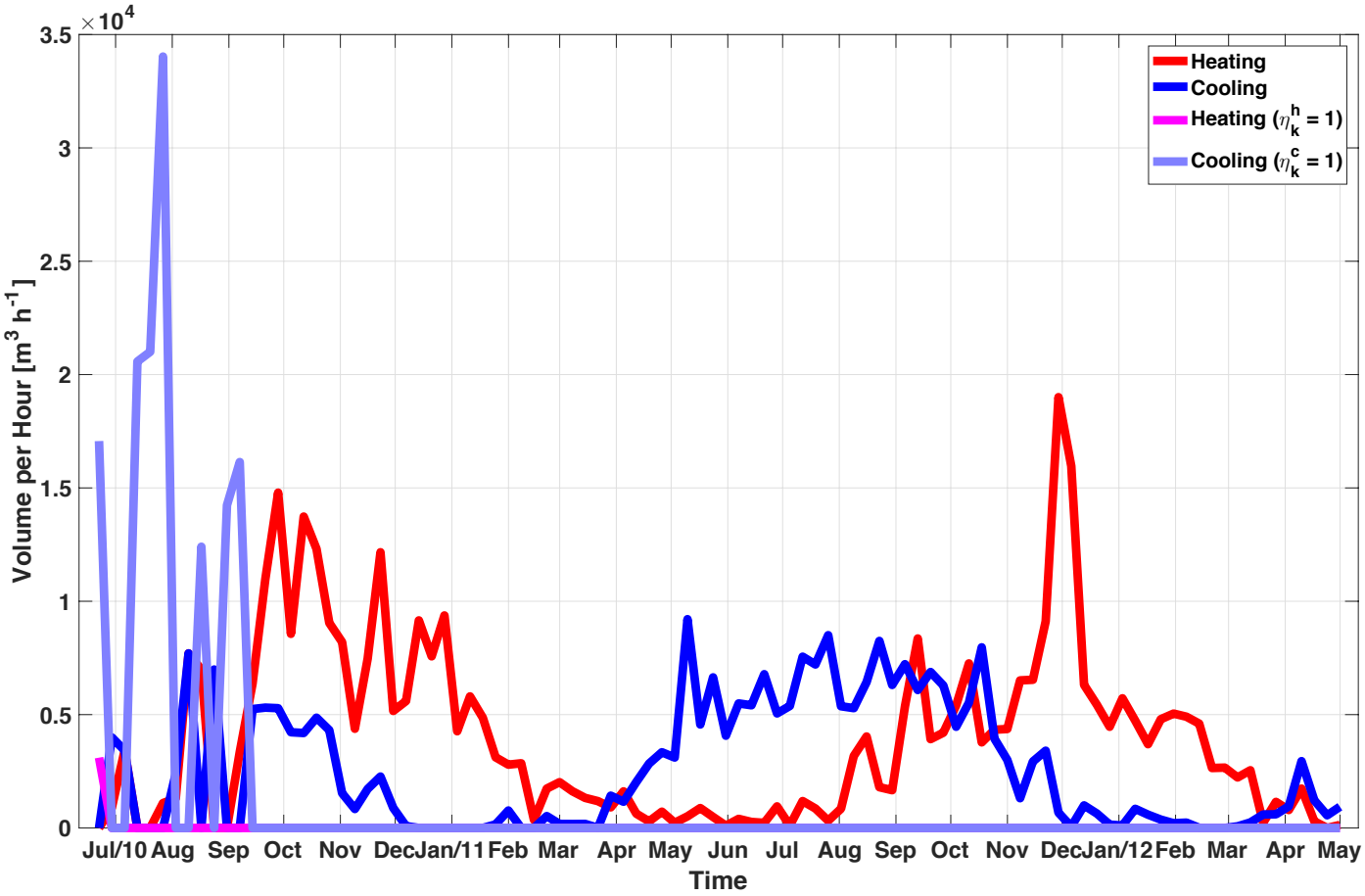
Simulations Results: Energy Content of ATES System

- ATES system starts with empty wells
- In July, by extracting from cold well with aquifer ambient temperature, the return water injected into warm well



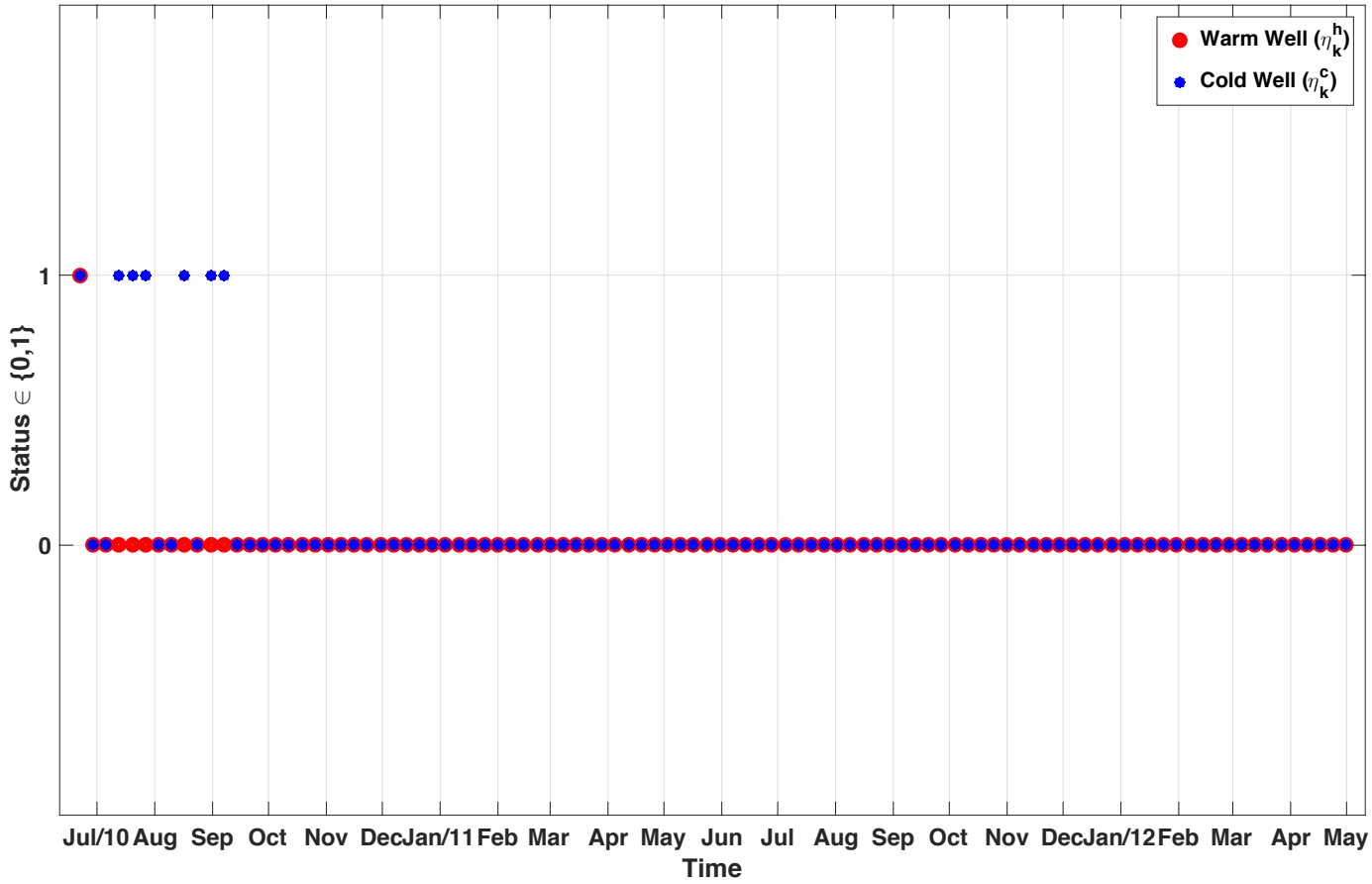
Simulations Results: Flow Rates of ATES System

- The lighter colors (red, blue) are related to pump flow rates during heating and cooling demand with empty ATES system
- Since ATES system is empty, it starts to pump with higher speed to provide more energy compared to normal condition



Simulations Results: Status Change of ATES System

- Status variables: empty warm well η_k^h and empty cold well η_k^c
- When ATES system wells are empty, the status variables have to been ON: $(\eta_k^h = 1)$ and $(\eta_k^c = 1)$



Outline

Concluding Remarks and Future Work

Remarks:

- A **practical predictive dynamical model** of ATES system

  Pros we can use such a model to predict behavior of the newly installed/completely depleted ATES system

  Cons such a model is a stochastic hybrid system (nonconvex program) and this leads a sub-optimal performance

- Simulation results showed **expected behavior**

What comes next:

1. Distributed Stochastic MPC in A Hierarchical Framework
   - higher layer to manage ATES systems in STGs
   - lower layer to provide desired comfort level for building control systems
2. Distributed Stochastic MPC in A Plug-and-Play Framework
   - buildings in ATES-SGs easily plug in/out to/from control framework

Scientific Output: Status Update

J1 Building Climate Energy Management in Smart Thermal Grids via Aquifer Thermal Energy Storage Systems
Published in Journal of Energy Procedia, Elsevier, 2016

S2 Tractable Reserve Scheduling Formulations for Alternating Current Power Grids with Uncertain Generation
MSc thesis (Ole ter Haar), DCSC, TU Delft. (2017, February)

C9 A Model Predictive Framework of GSHP coupled with ATES System in Heating and Cooling Networks of a Building
Accepted to the IEA Conference on Heat Pump, Rotterdam, The Netherlands. (2017, May)

C10 A Set Based Probabilistic Approach to Threshold Design for Optimal Fault Detection
Accepted to American Control Conference (2017, June)

C11 Energy Management for Building Climate Comfort in Uncertain Smart Thermal Grids with ATES
Accepted to IFAC World Congress 2017 (2017, July)

C12 Tractable Reserve Scheduling in AC Power Systems With Uncertain Wind Power Generation
Submitted to Control Decision Conference 2017

C13 Distributed Stochastic Model Predictive Control Synthesis for Large-Scale Uncertain Linear Systems
Submitted to Control Decision Conference 2017

Scientific Output: Status Update

Under Preparations:

J2 Probabilistic Energy Management for Building Climate Comfort in STGs with Seasonal Storage Systems
Expected Date: June 2016

J3 Distributed Stochastic Reserve Scheduling in AC Power Systems with Uncertain Generation
Expected Date: June 2016

J4 Differentially Private Distributed Anomaly Detection Using A Set Based Probabilistic Approach
Expected Date: July 2016

Under Progress:

- Distributed Stochastic MPC Synthesis for A Networked of Coupled Uncertain Agents
- Distributed Stochastic MPC in A Hierarchical Framework for A Networked of Stochastic Hybrid Systems
- A Set Based Probabilistic Approach to Fault Detection and Isolation for Uncertain Nonlinear Systems

ATES System: A Practical Predictive Dynamics Model

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Delft University of Technology
Delft Center of Systems and Control

Users' Group Meeting

June 6, 2017