Title
Renewable Energy Integration

Author
Prof. Alexandra von Meier

Publication Date
2010

Enabling Technologies Development Project
September 14, 2010

Renewable Energy Integration

Dr. Alexandra von Meier
Research Coordinator, CIEE
Professor, Sonoma State University

This work was funded by CIEE Subaward No. POB231-B45, Contract No. 500-99-013

Fundamental challenge:

Renewable and distributed resources introduce **spatial and temporal constraints** on resource availability, which legacy power systems were not designed to address.

Addressing these constraints will require new efforts at **spatial and temporal coordination** of resources and capabilities within the electric grid, both to **mitigate difficulties** and to **maximize benefits**.

Coordination Dimensions

Spatial coordination:

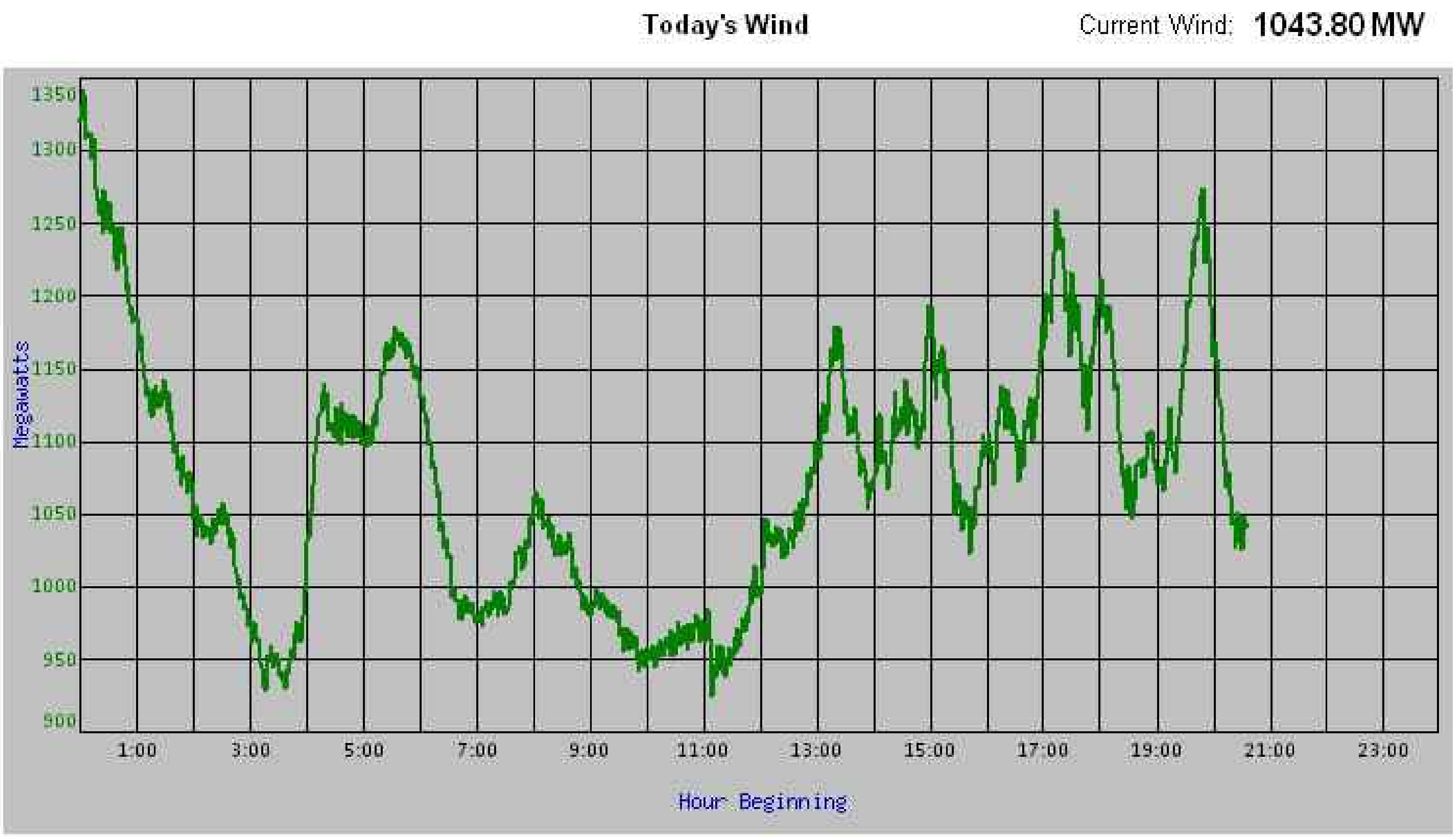
How resources are **interconnected** and their **location-specific effects** controlled

Issues involve transmission links, distribution infrastructure

Temporal coordination:

How the **time-varying behavior** of resources is addressed

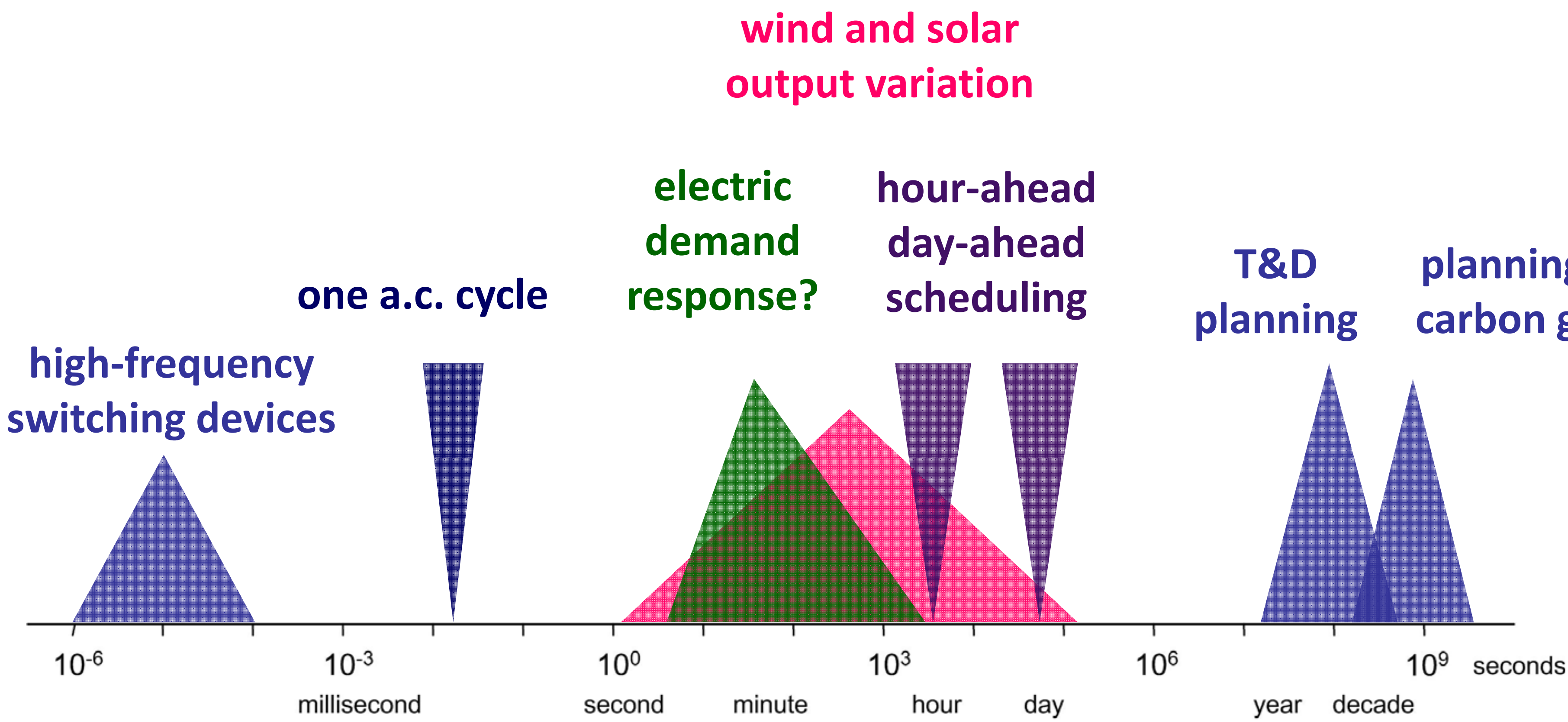
Issues involve grid stability, optimal use of a large variety of firming resources



This graph shows the aggregated output from the wind generation connected directly to the California ISO Balancing Area.

Temporal Coordination

Comparative time scales

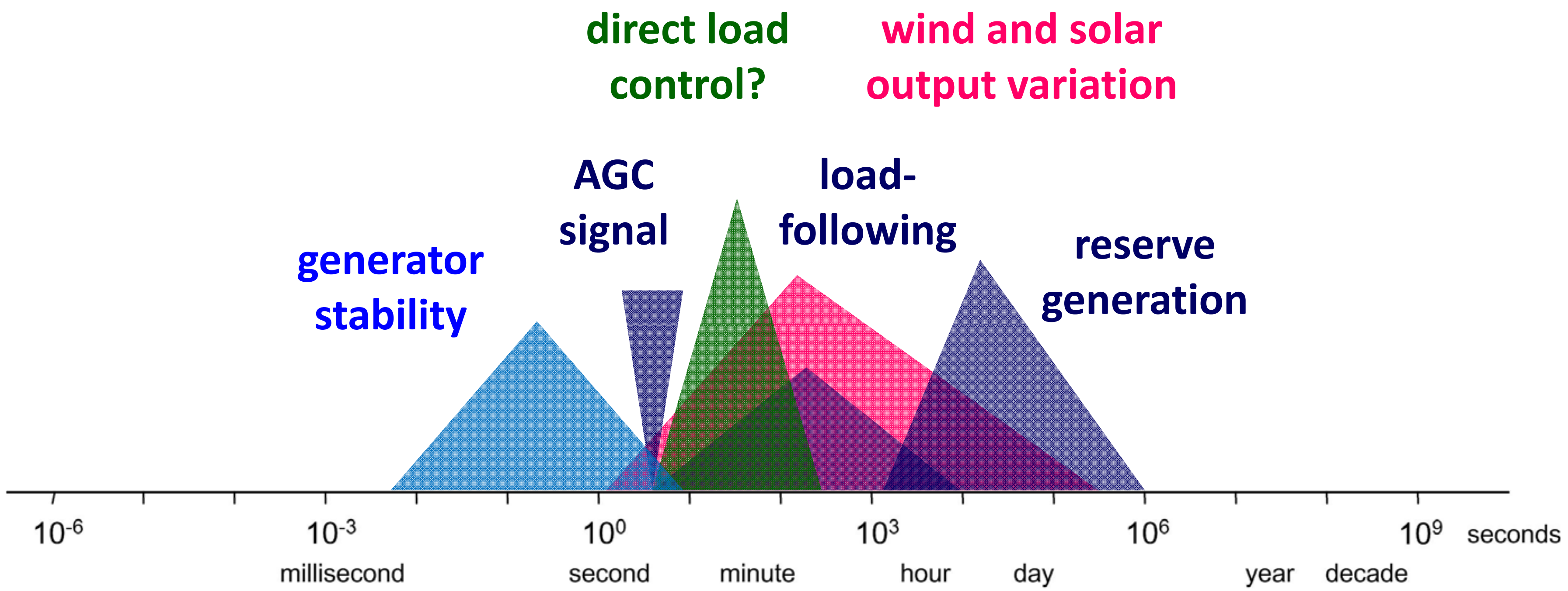


Firming resources for intermittent renewables:

- reserve generation capacity
- dispatchable generation with high ramp rates
- generation with regulation capability
- dispatchable electric storage
- **electric demand response**

Firming Resources and Up-Down Regulation

- ramp rates in MW/s?
- time for control signal?



UC Berkeley Research

Prof. Dave Auslander & Prof. Duncan Callaway

Goal: accomplish demand response for up-down regulation via **direct load control**

✓ **down to 5-second time scale**

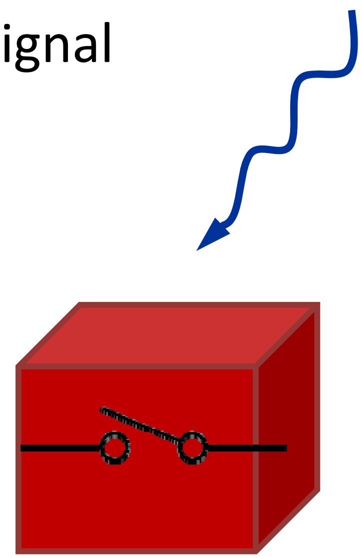
✓ **without impacting end-use** (!)

Enabling technologies:

- communications hardware
- communications protocols
- **control algorithms**

Direct Load Control Hardware

No major appliance modification needed,
only a connector between plug and wall outlet
capable of
- receiving radio signal
- disconnecting



Installation crux: access plug behind fridge

Bonus: opportunity to clean coils!

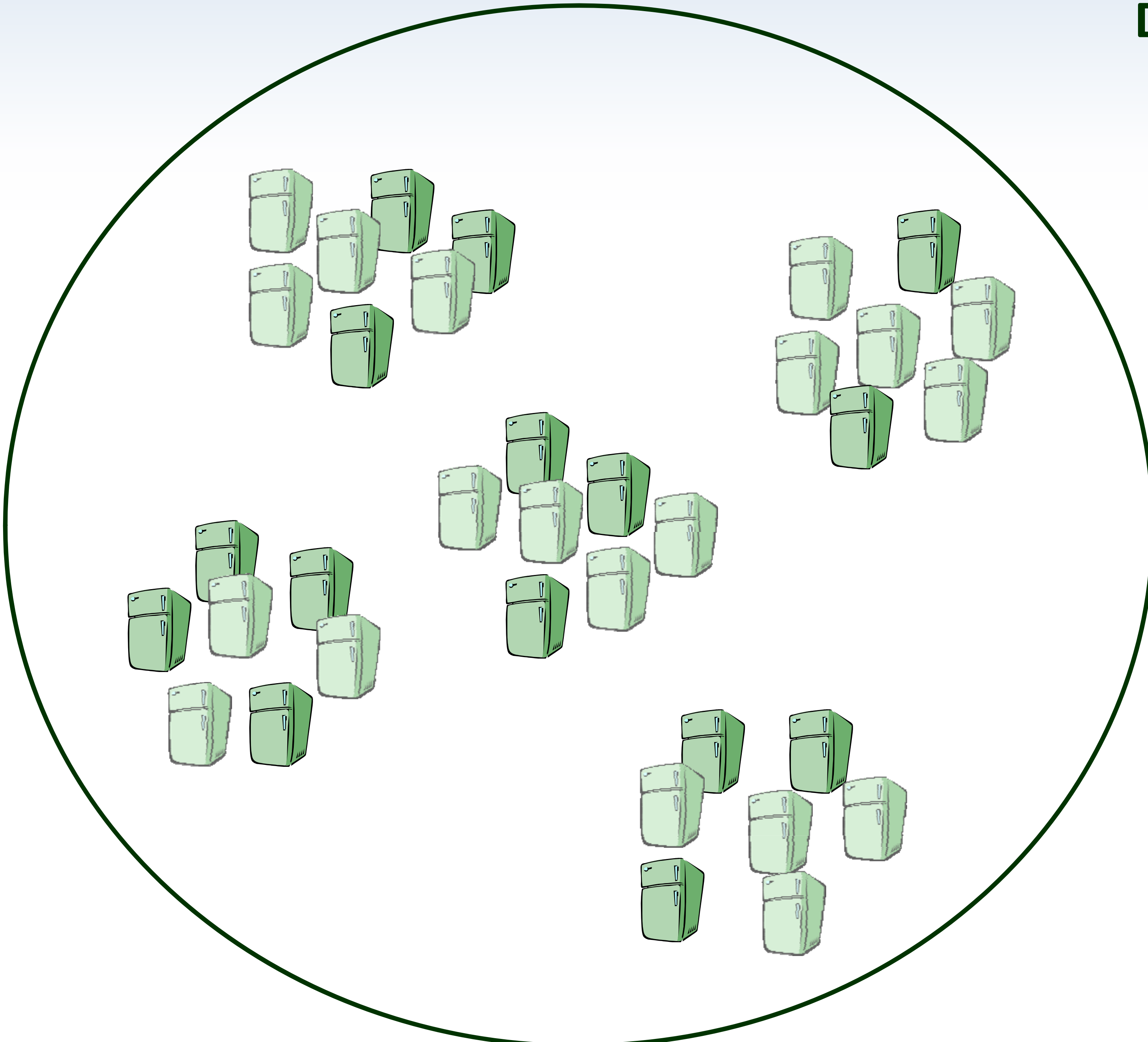
Direct Load Control

Goal:
attain up/down response in aggregate power, **without users noticing change** in appliance performance (e.g. water or food temperature)

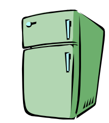
Aggregate response should be
rapid & predictable
but distributed so that individual devices are **minimally affected**

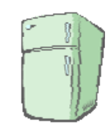
Device population
N = 10,000

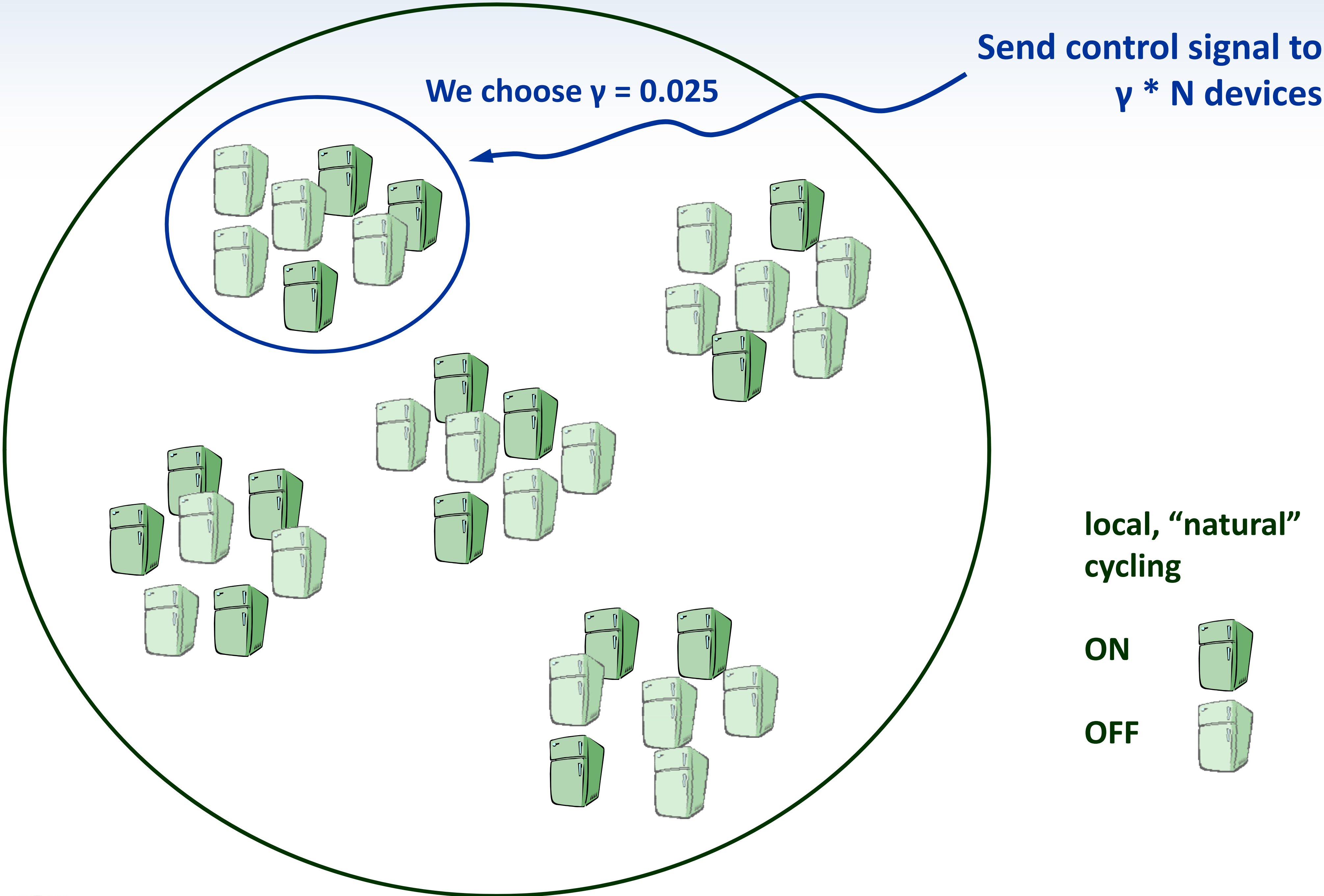
Refrigerator cycle time
~40 minutes



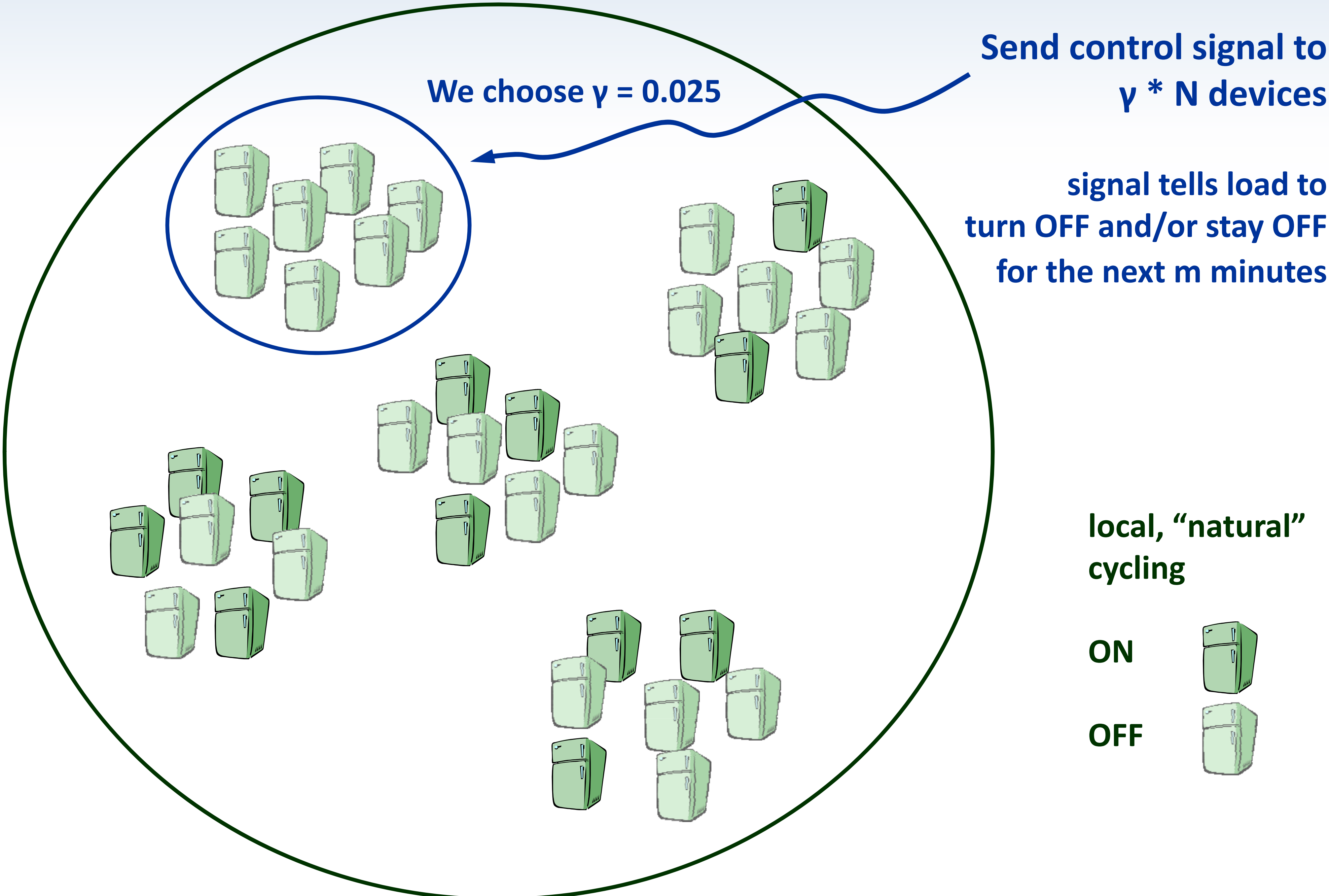
local, "natural" cycling

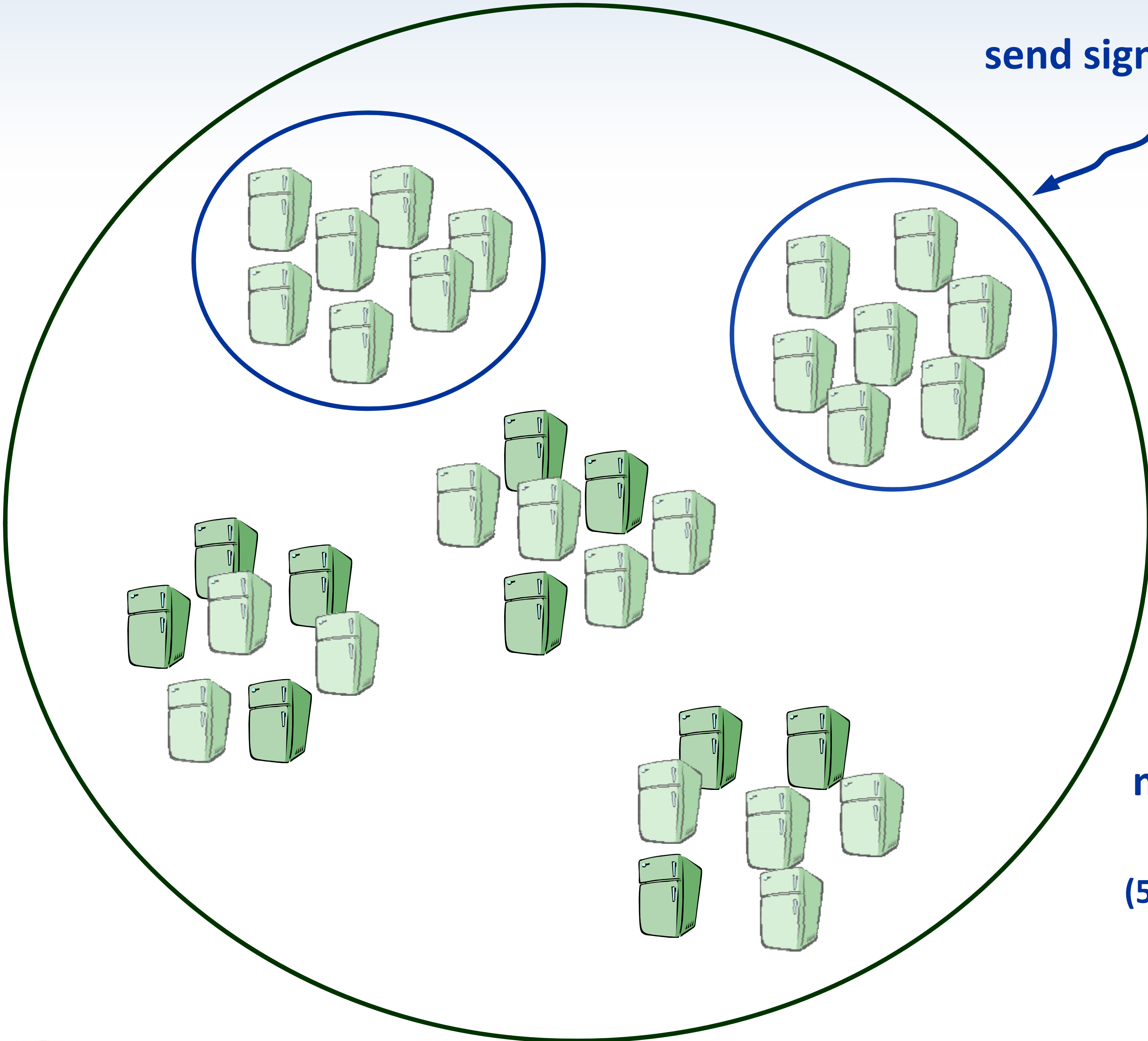
ON 

OFF 



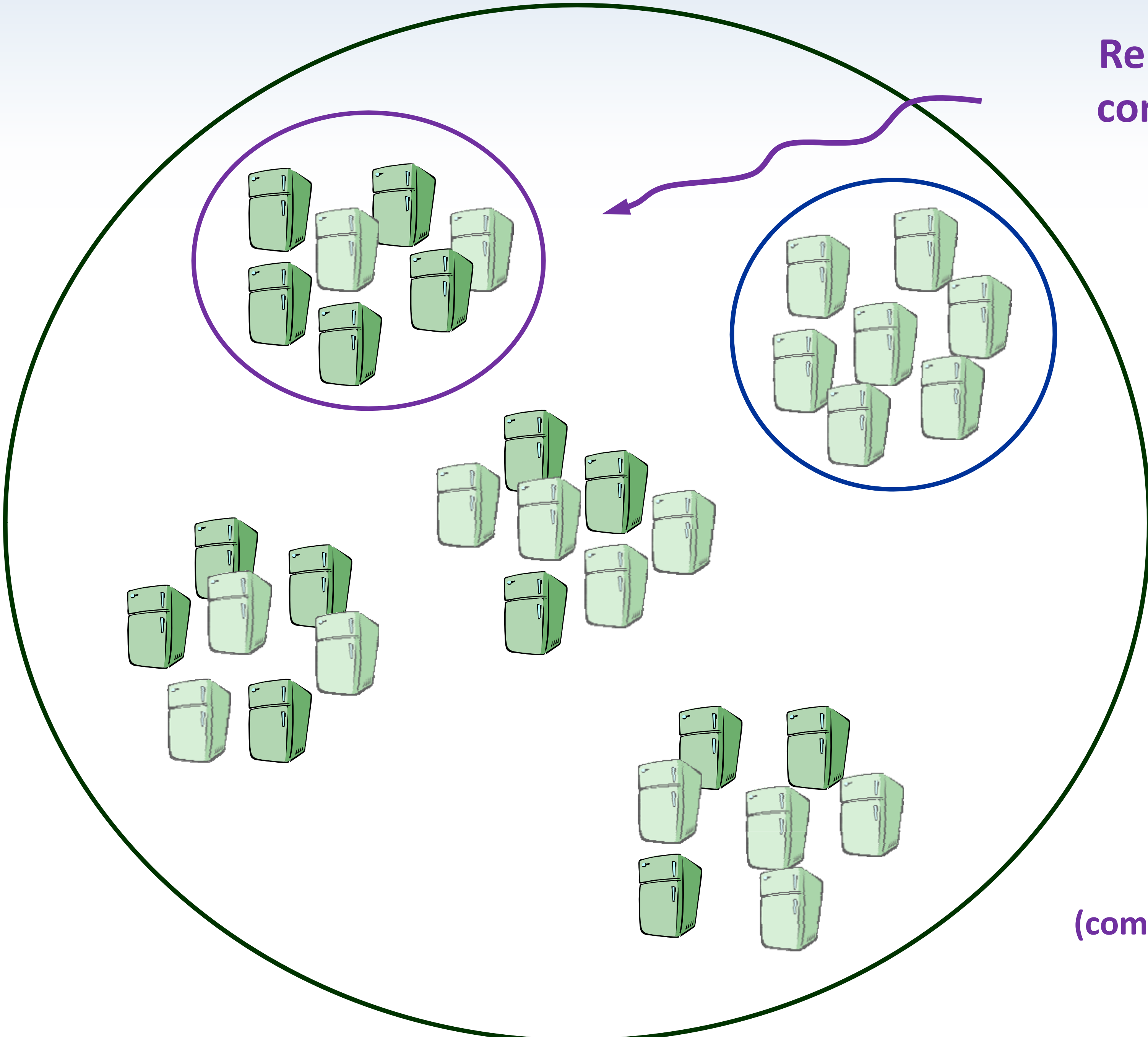
Send control signal to
γ * N devices
We choose γ = 0.025
local, "natural"
cycling
ON
OFF


Send control signal to
γ * N devices
We choose γ = 0.025
signal tells load to
turn OFF and/or stay OFF
for the next m minutes
local, "natural"
cycling
ON
OFF



send signal to γ * N devices in the next control time step
(1 minute)

At any one time, m * γ * N devices are being controlled off
(5 * 0.025 * 10,000 = 1250)

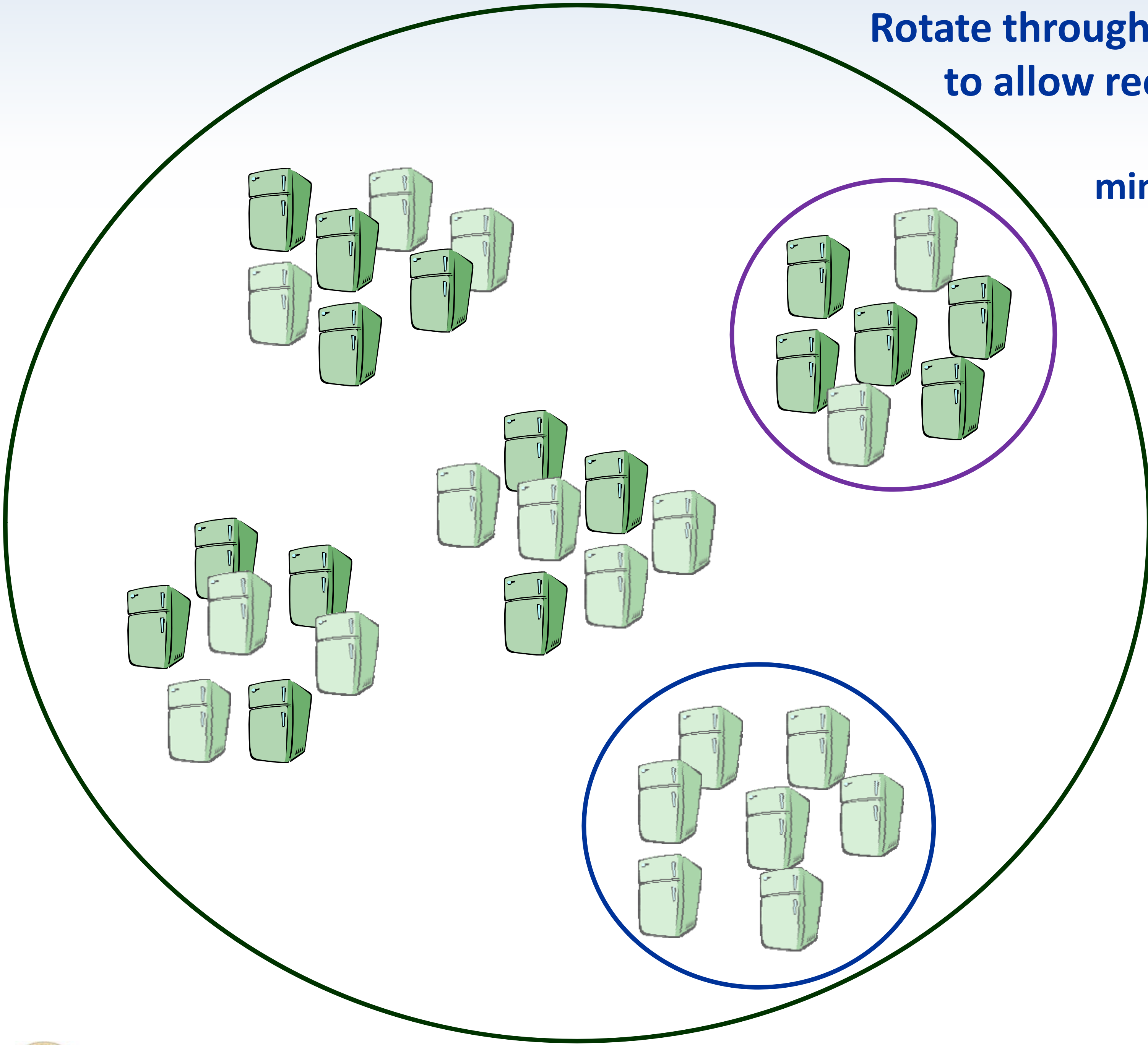


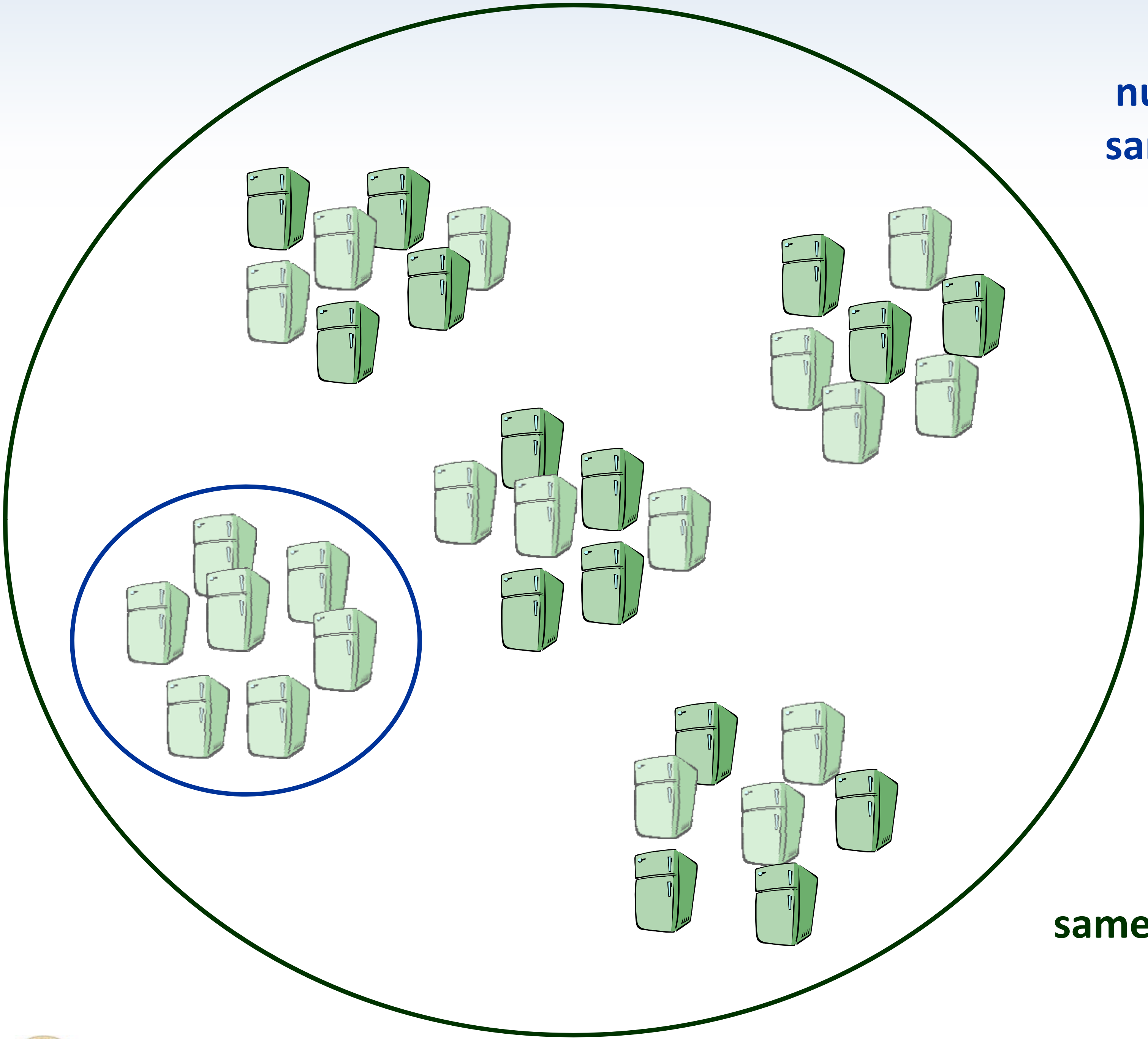
Release devices to local control after m minutes
(m = 5 minutes)

Devices released from control tend to rebound
(compensating for heat lost or accumulated)

Rotate through devices sequentially to allow recovery time between control turns:

minimize noticeable effect on device performance





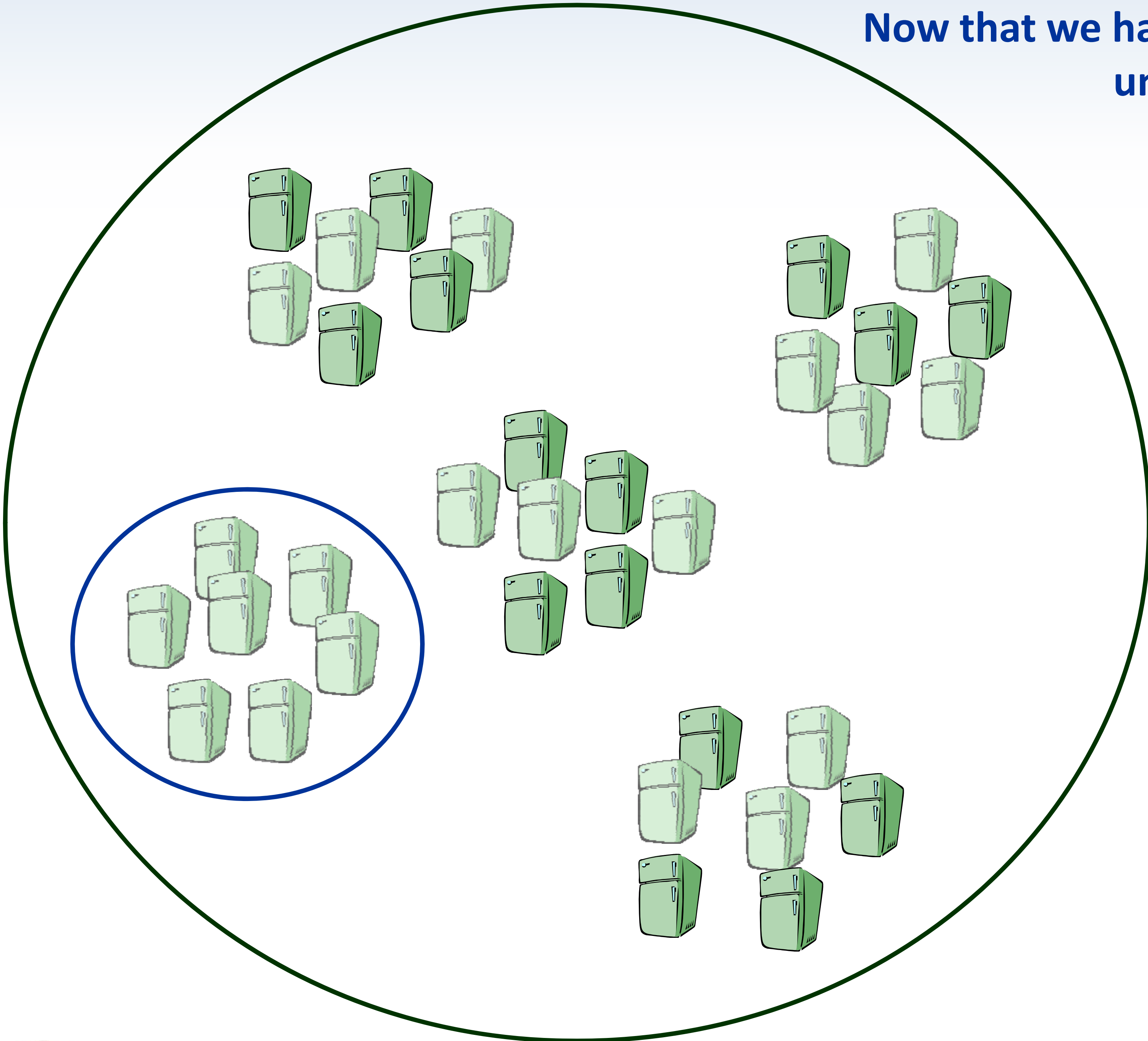
Equilibrium:
number of devices ON
same as before control

but ordered in
rotating groups

current controlled
devices are OFF
other devices average
slightly more ON

aggregate power
same as without control

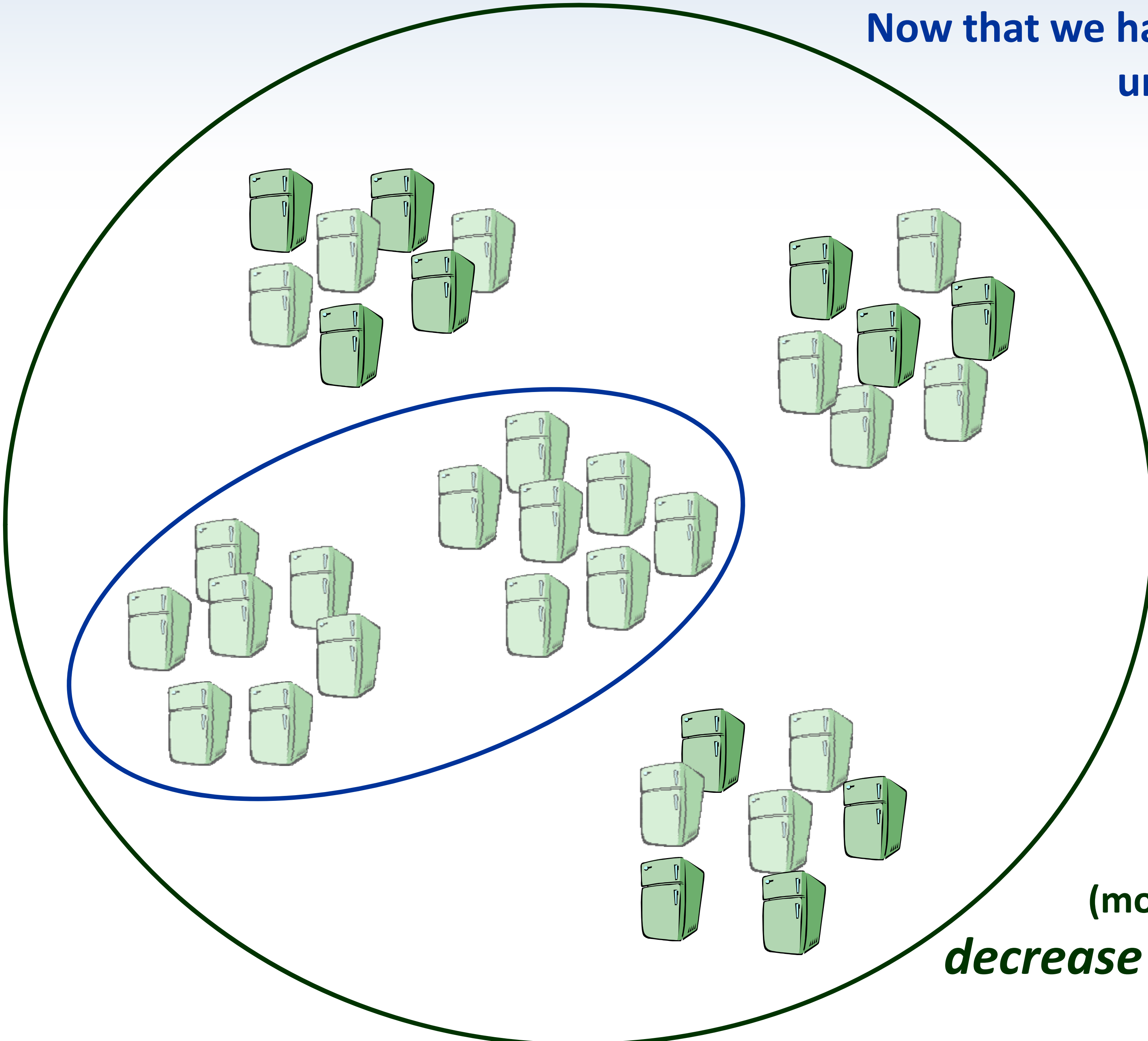
Now that we have entire population
under rotating control,
we may change γ
to disturb population
from equilibrium



Now that we have entire population under rotating control,

we may change γ

to disturb population from equilibrium

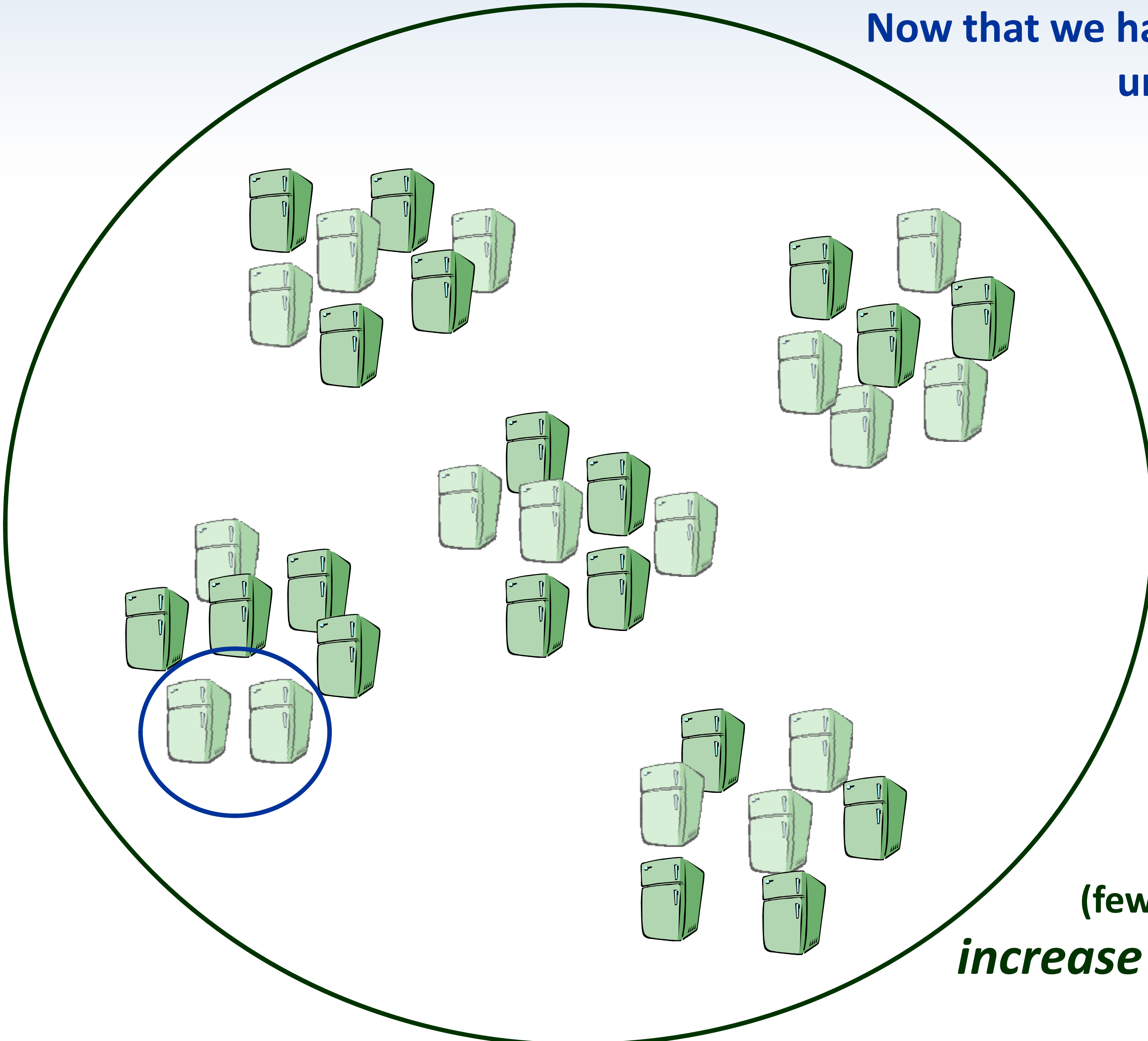


increase γ

(more devices OFF at once)

decrease aggregate power

temporarily



Now that we have entire population under rotating control,

we may change γ

to disturb population from equilibrium

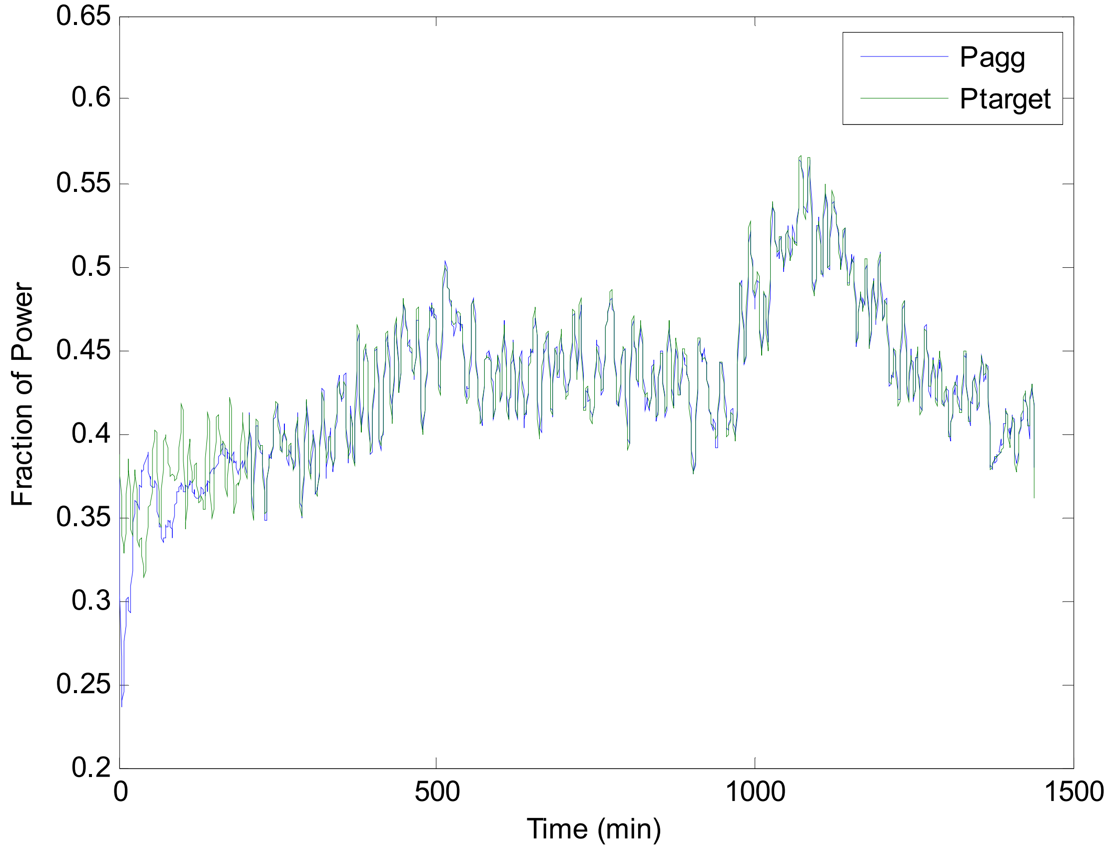
decrease γ

(fewer devices OFF at once)

increase aggregate power

temporarily

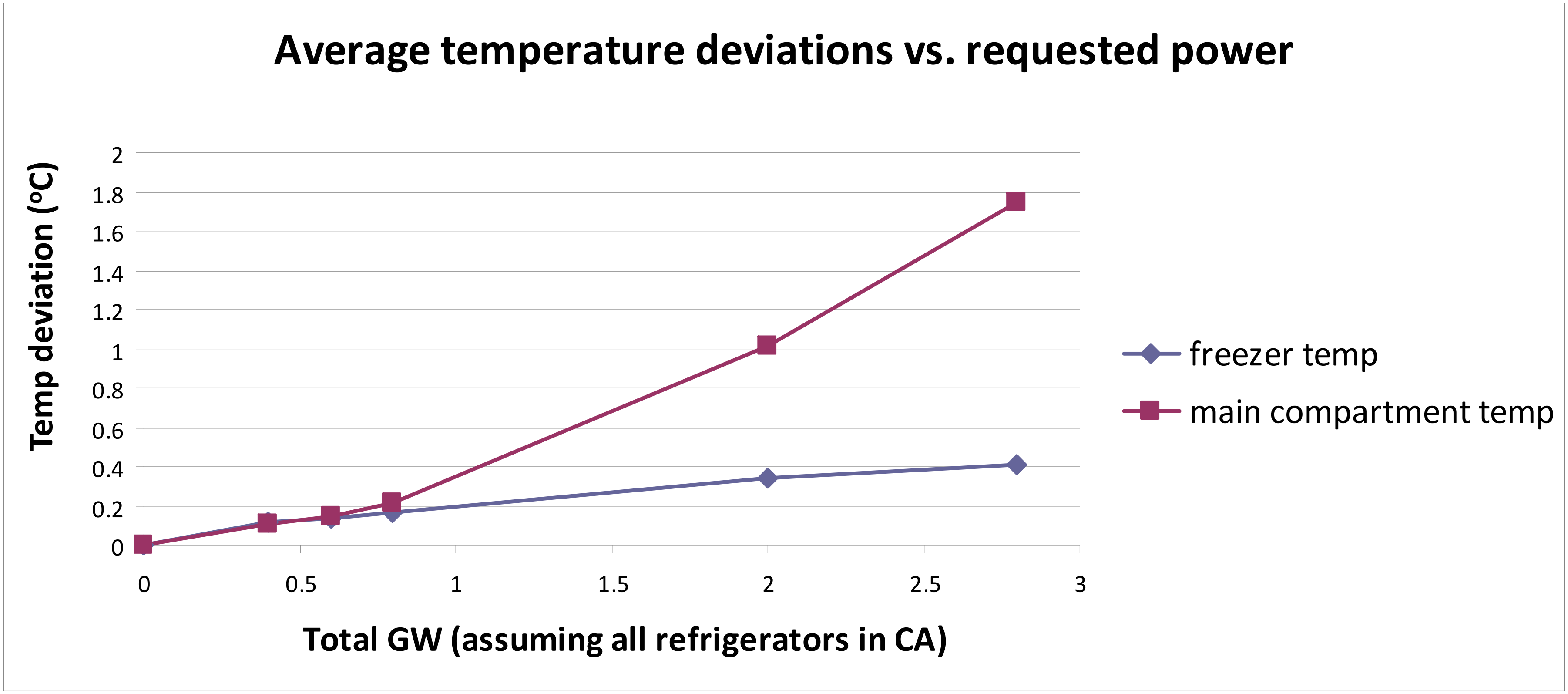
Results: Minimum Variance Controller



P_{agg} = aggregate power (10,000 devices)

P_{target} = profile to be tracked

such as ACE or unforecasted component of wind



Average temperature deviations vs. requested power
Temp deviation (ºC)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
Total GW (assuming all refrigerators in CA)
freezer temp
main compartment temp

Conclusion:

Rapid demand response for up-down power regulation could actually work!

Potential to provide on the order of 1 GW:

750 MW from CA refrigerators plausible without adverse effects

2 MW worth investigating

Enabling technologies:

- communications hardware
- communications protocols
- **control algorithms**

Continuing work:

Improve models and control strategies to

- **improve accuracy of MW regulation**
- **reduce end-use impact for a given level of aggregate capacity**

Future:

Field test in collaboration with partners