

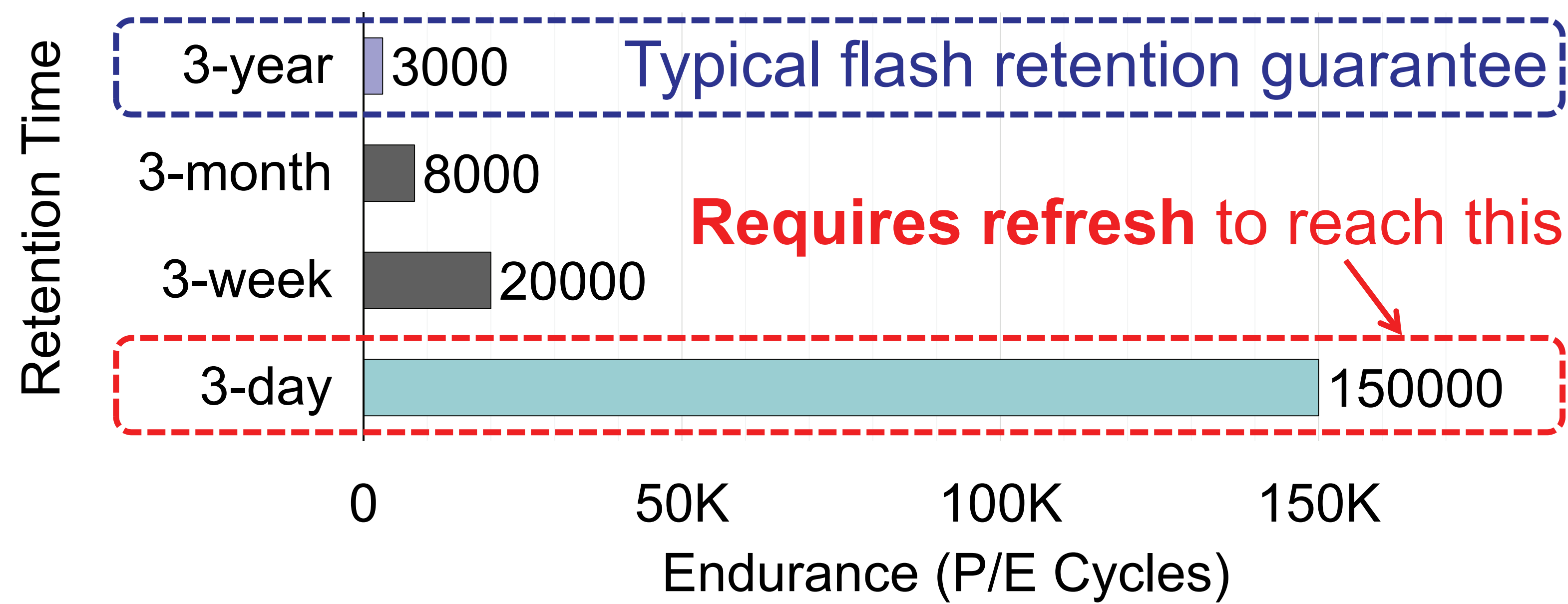
# WARM: Improving NAND Flash Memory Lifetime with Write-hotness Aware Retention Management

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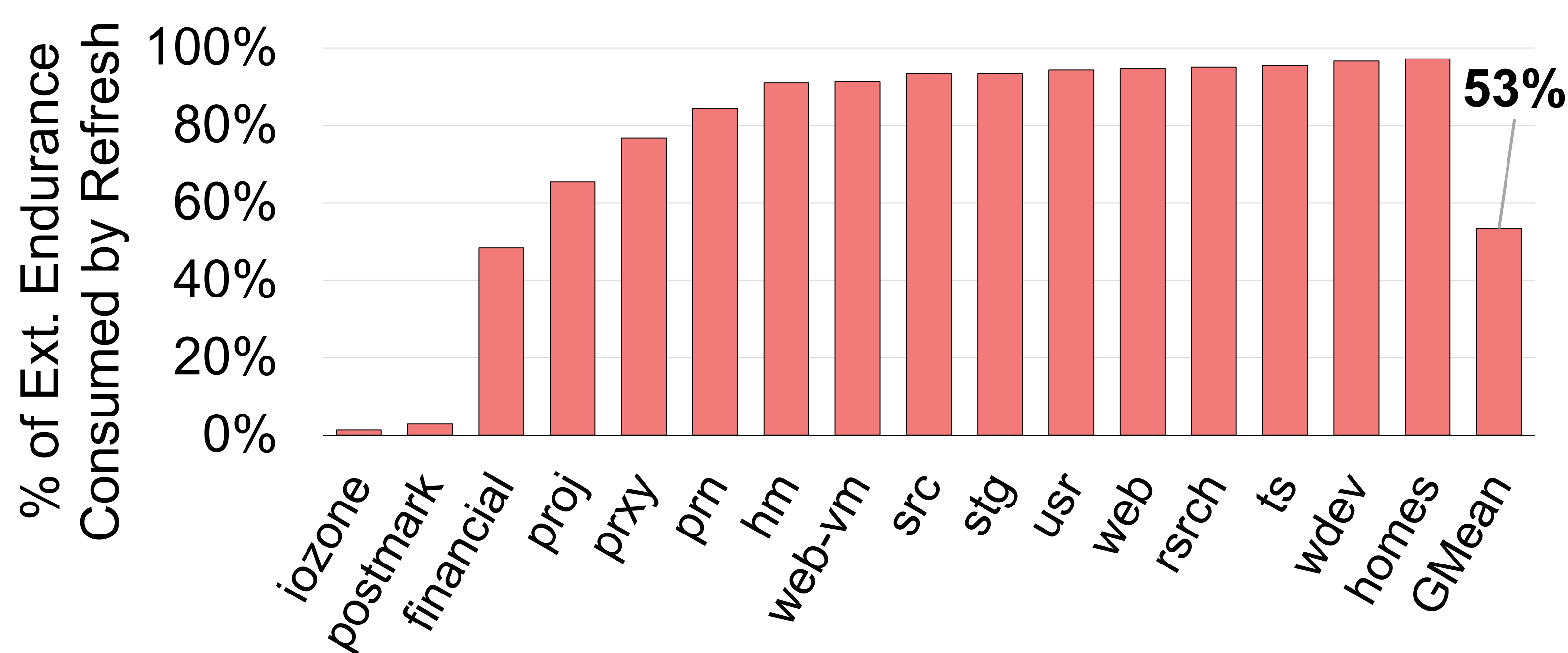
## Motivation

**Background:** Relaxing *internal retention time* of flash memory improves lifetime



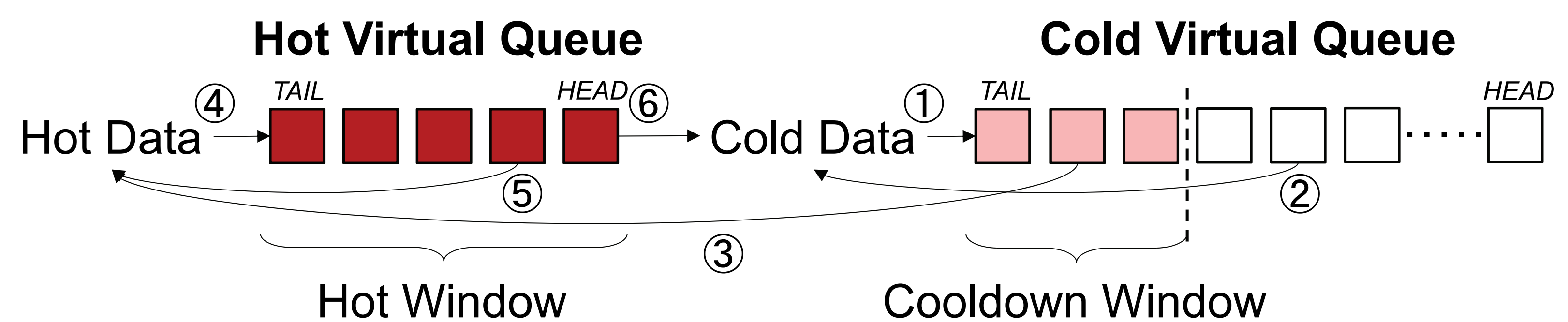
**Problem:** Refreshes typically required to guarantee data integrity, but consume additional writes →

**potential lifetime improvements restricted**

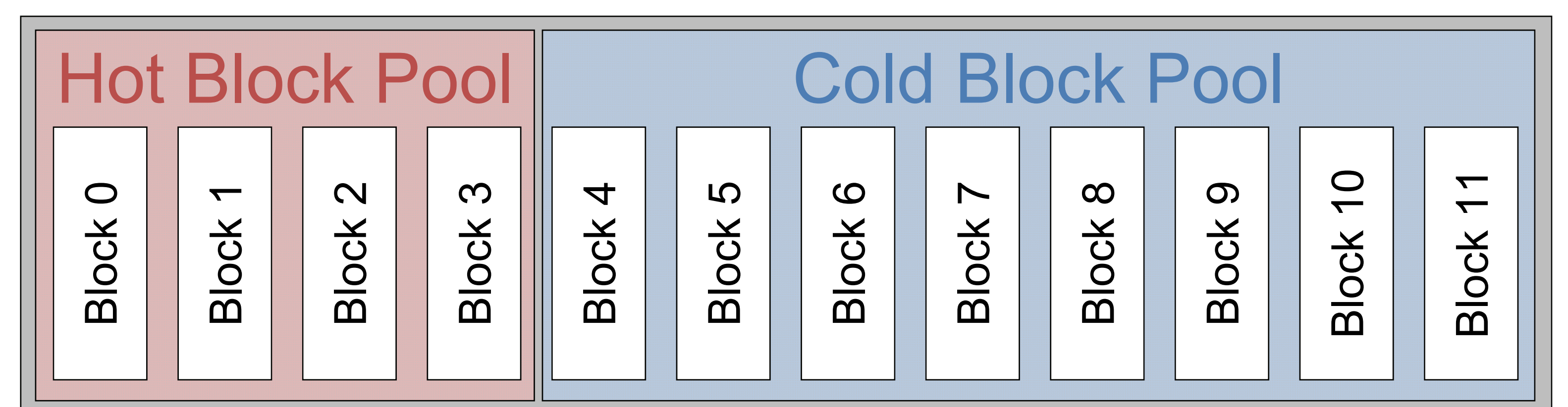


## WARM: Write-hotness Aware Retention Mgmt.

- Physically partition pages into two groups using **write frequency**: *write-hot* and *write-cold*
  - Virtual queues for dynamic page reclassification
  - Cooldown window to minimize ping-ponging



- Apply different policies (garbage collection, wear-leveling, refresh) to each group



### Write-hot Data

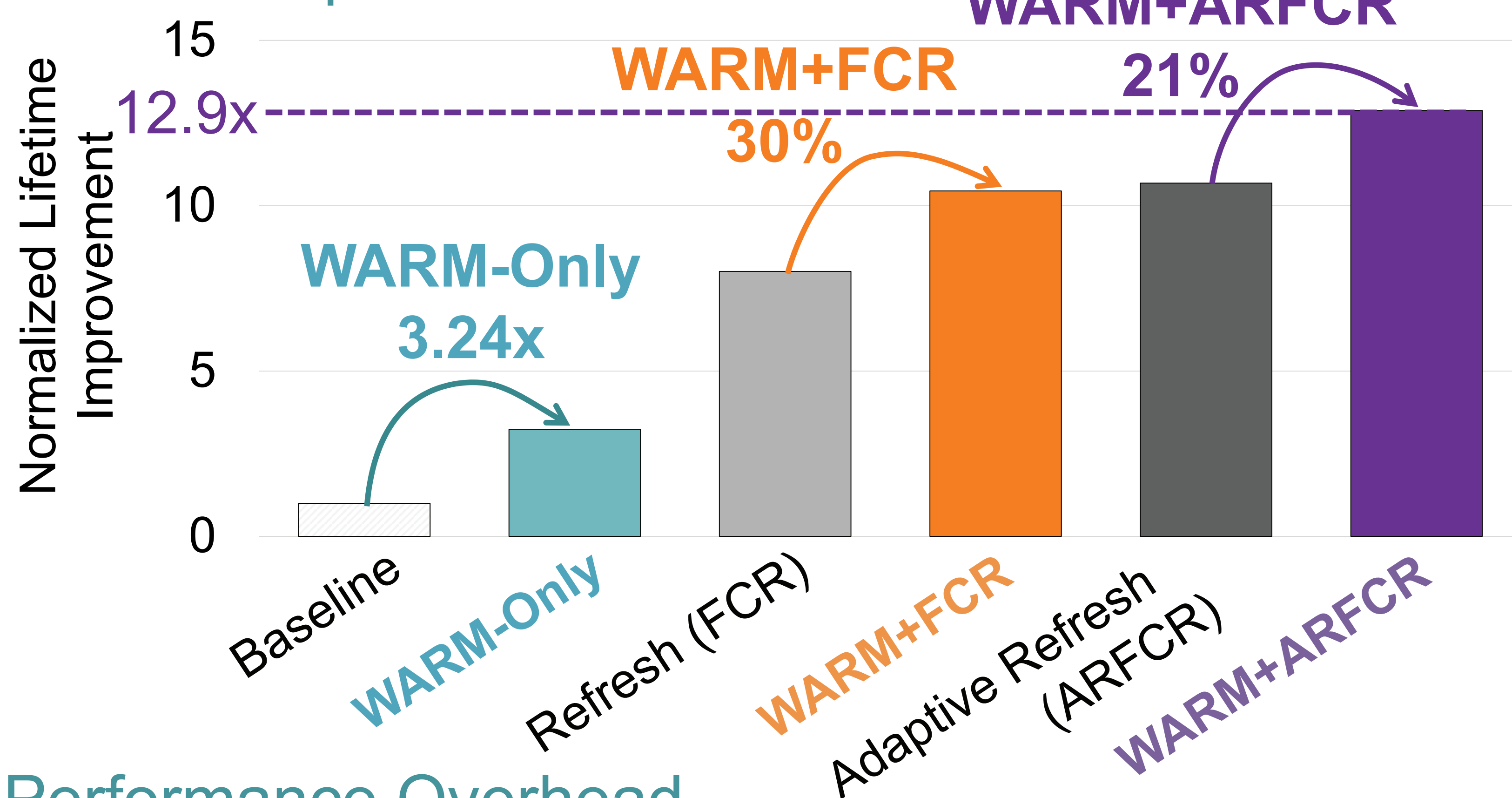
- Naturally relaxed retention time – **no refresh needed**
- Program and garbage collect in block order
- Naturally wear-leveled

### Write-cold Data

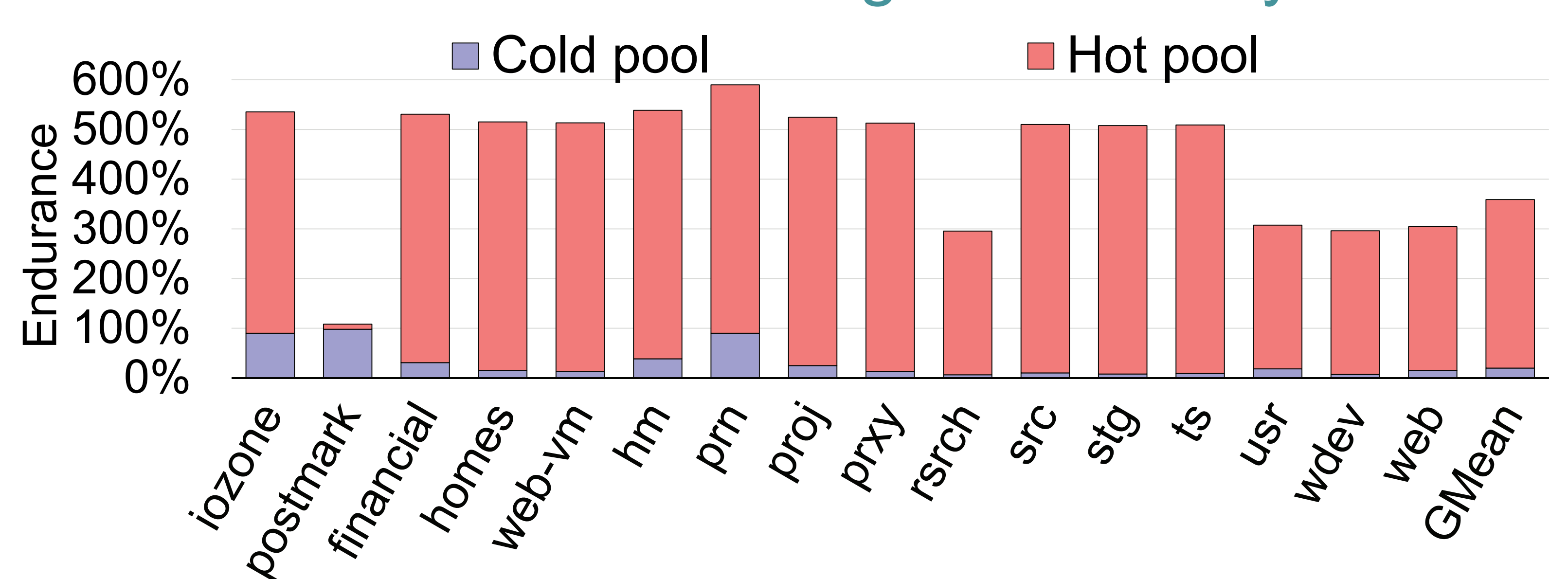
- Low write frequency → slower wear-out
- Conventional garbage collection and wear-leveling

## WARM Results

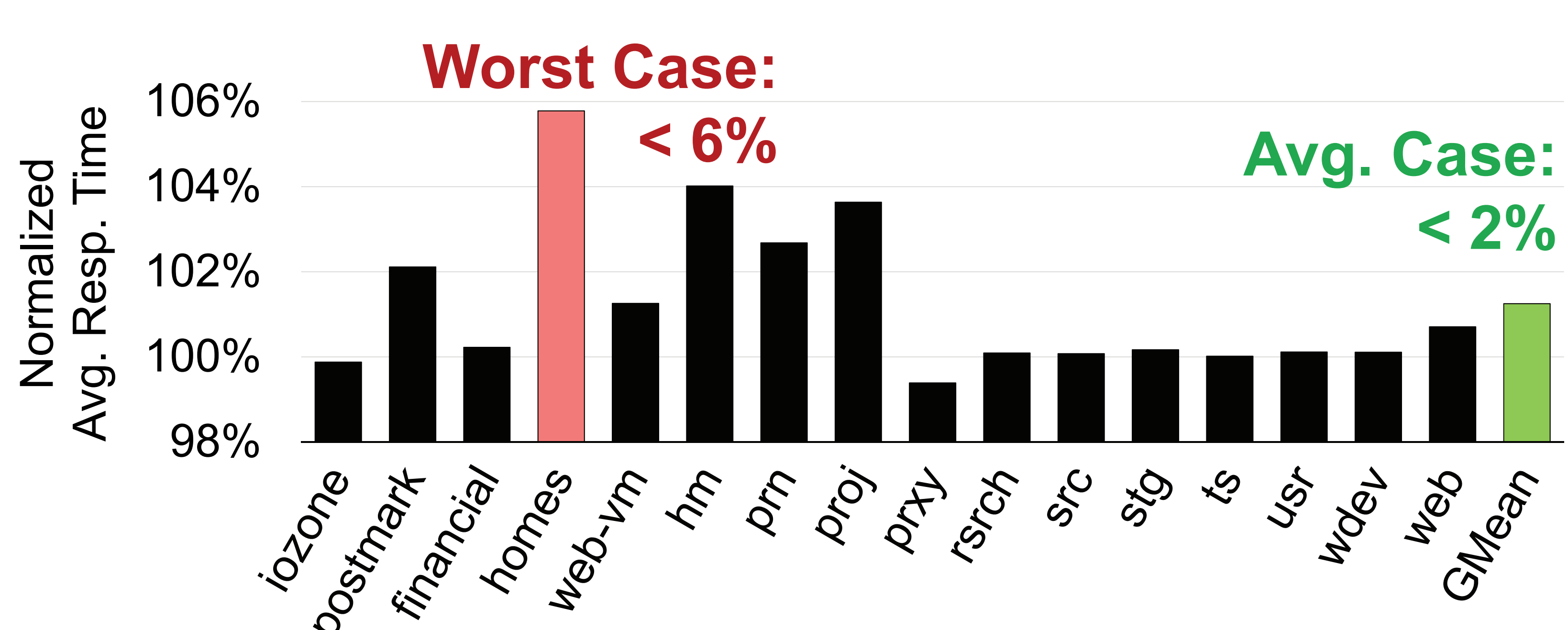
### Lifetime Improvements



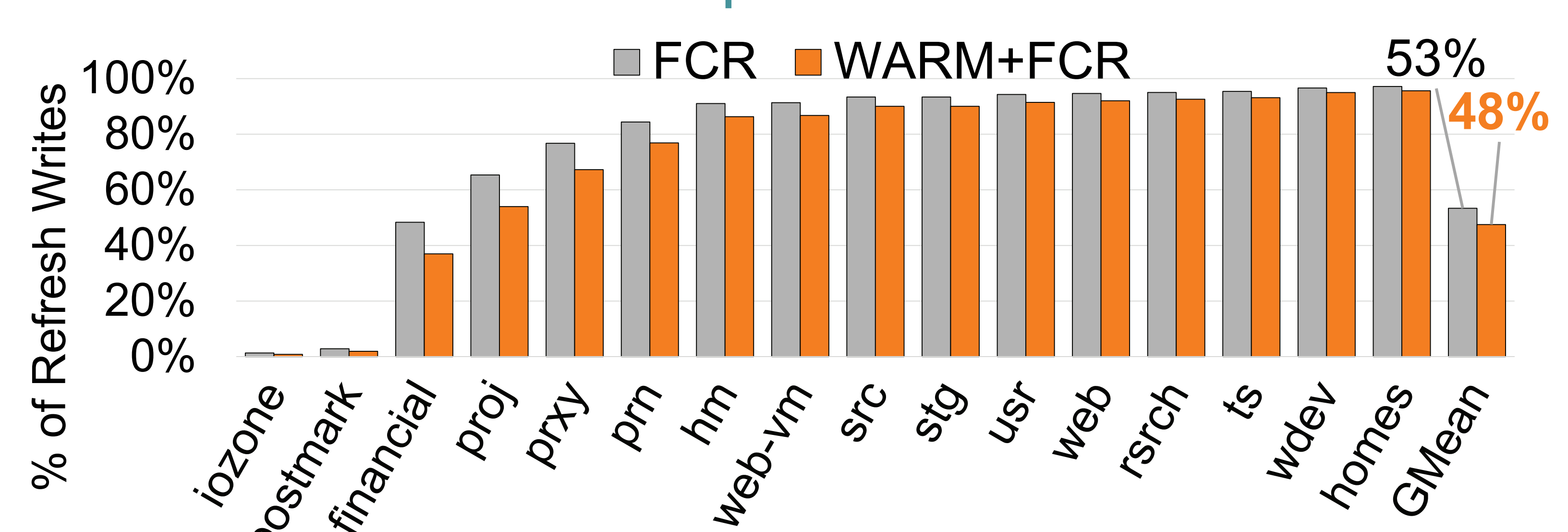
### Increase in Endurance Using WARM-Only



### Performance Overhead



### Reduction in Refresh Operations w/ WARM



### Hardware Overhead

- Four 32-bit counters to dynamically tune the window
- 1.03 KB memory to track blocks in hot pool, cooldown