



Energy-Adaptive Display System Designs for Future Mobile Environments

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Motivation

Displays consume significant power in mobile systems

- 50% on laptops^[7], 61% on handhelds^[1]

Motivation

Previous approaches:

- Turning off the entire display
- Using lower quality or smaller sized displays

Our approach: [Energy-Adaptive Display](#)

- Power consumption based on content being displayed
- Adapt display content to match user needs

Contributions

Contribution

Characterization of display usage patterns

- Only 60% screen area has user's focus
- User needs mismatch display properties

Energy-adaptive display system designs

- Leverage emerging display technologies
- Prototype user interface optimizations
- Model power benefits
- Study user experience

Energy study based on display usage patterns

- 40% reduction of display power consumption

Outline of talk

Motivation and Contributions

User study

- Methodology
- Results

Energy-adaptive display design

- Hardware and software support
- Prototyping the user interface
- Evaluation methodology
- Power estimation

Discussion and Conclusions

Methodology for the user study

User Study

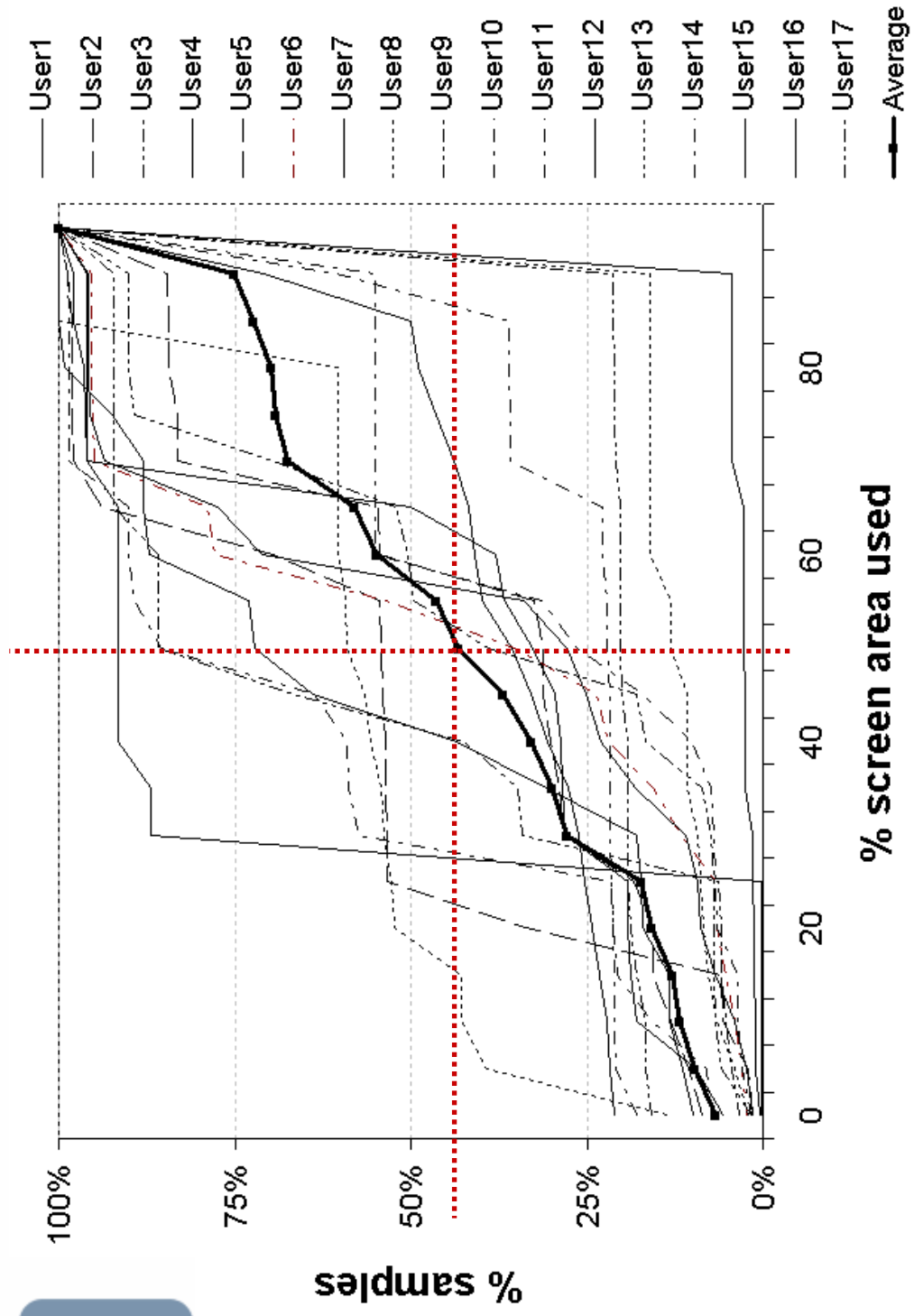
Scope: 17 representative users

- Researchers, developers, assistants
- Use both desktops and laptops
- Environment: Microsoft Windows
- Various screen sizes and resolutions

Logger program collects:

- Window-of-focus (size, location, title)
- Screen area used (non-minimized windows)
- 1 sample per second
- 100 days of samples in total
- ~600 hours of non-idle samples

User study results



User study results (cont.)

User Study

User needs mismatch display properties

Display size is not fully utilized:

- Average window-of-focus: 58.8%
- Average background window(s): 16.7%

Other mismatches:

- Resolution
- Brightness
- Color

Power can be reduced without loss in visual quality!

Outline of talk

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Energy-adaptive display design

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Discussion and Conclusions

System design – hardware support

Key requirement:

- Display power determined by screen output

Organic Light Emitting Diode (OLED) displays:

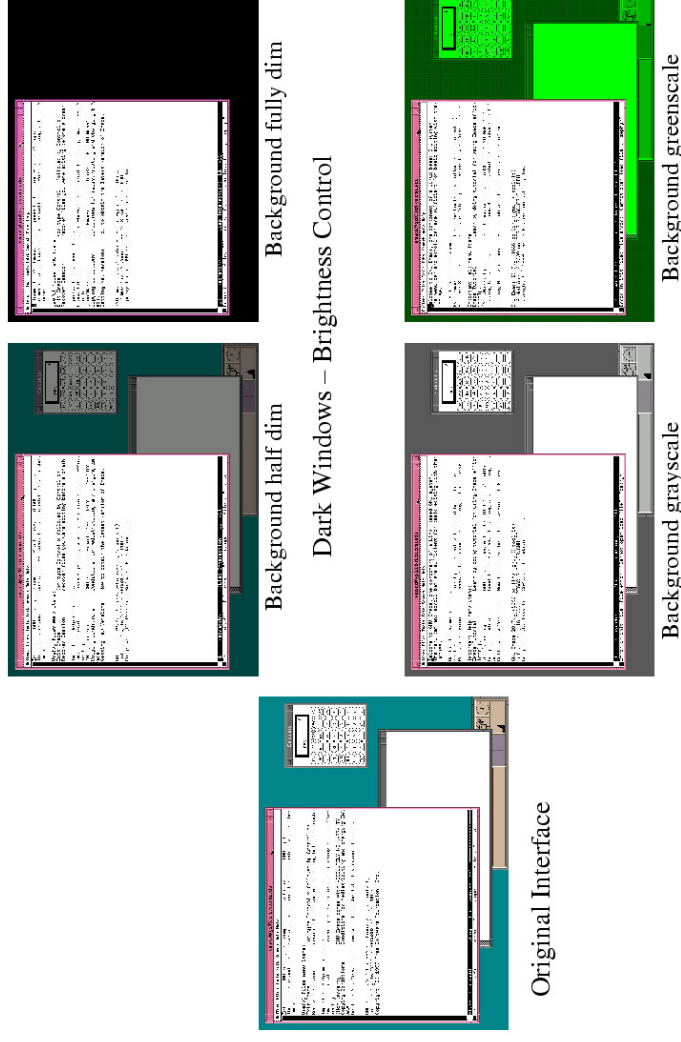
- Pixel power based on pixel value (brightness and color)
- Better image quality
- No backlight needed
- Cell phones currently
- Handhelds and laptops in 2004

Assume a laptop system with 15" active matrix OLED

System design – software support

User Interface optimization: “Dark Windows”

- Automatic power-aware adaptation of brightness and color
- Not modified: window-of-focus
- Modified: remaining screen areas



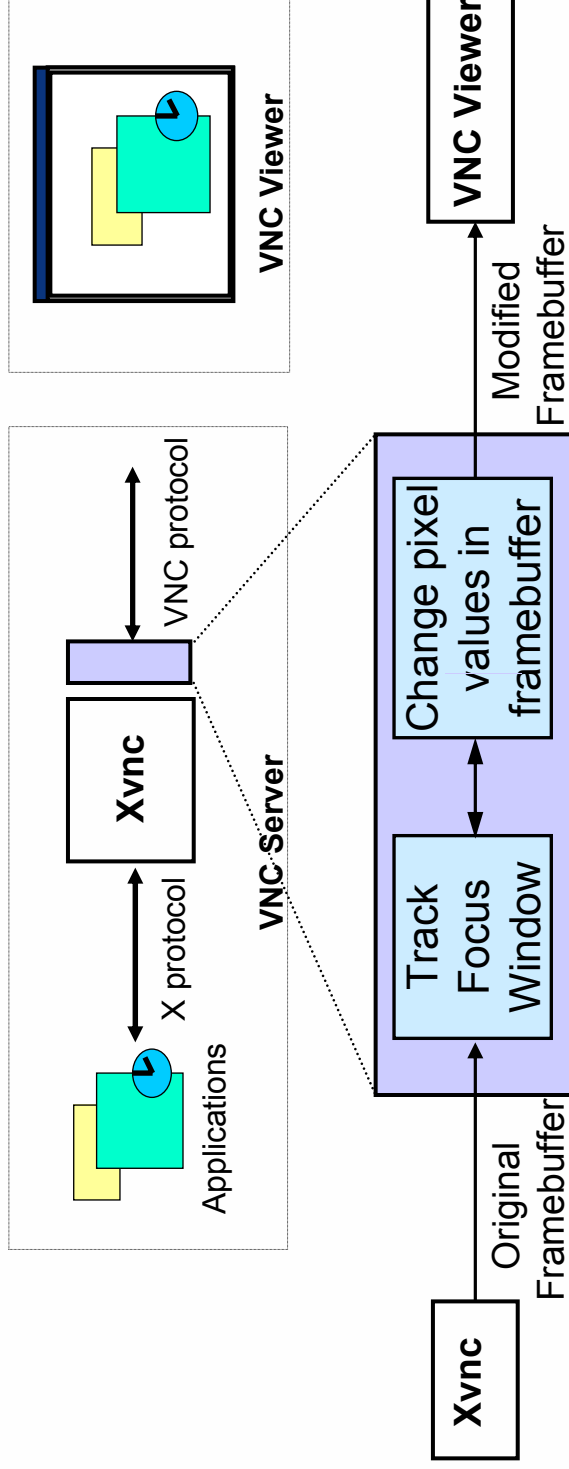
Dark Windows – Color Control

Prototyping the user interface

Based on X Window System under Linux

Prototype

- Use open-source VNC for clean implementation
 - Virtual representation of the display hardware
 - Access to X-Window server data structures
 - Easy to manipulate the pixel values



Evaluation methodology

Goals:

- Understand user intrusiveness
- Quantify energy benefits

Methodology:

- Based on user study results
- Create synthetic trace modeling average user behavior
- Include a set of similar applications
- Replay the behavior on prototyped interface
- Experiment on different UI optimizations

Power model

15" OLED displays not available

Representative software power model:

- OLED datasheets
- Display experts

$$\text{Display Power} = P_{\text{controller}} + P_{\text{driver}} + \text{Panel Power}$$

$$\text{Panel Power} = \text{Pixel Array Power}$$

$$= \sum_{\text{all_pixel}} (P_{\text{red}} \times \text{pixel}_R + P_{\text{green}} \times \text{pixel}_G + P_{\text{blue}} \times \text{pixel}_B)$$

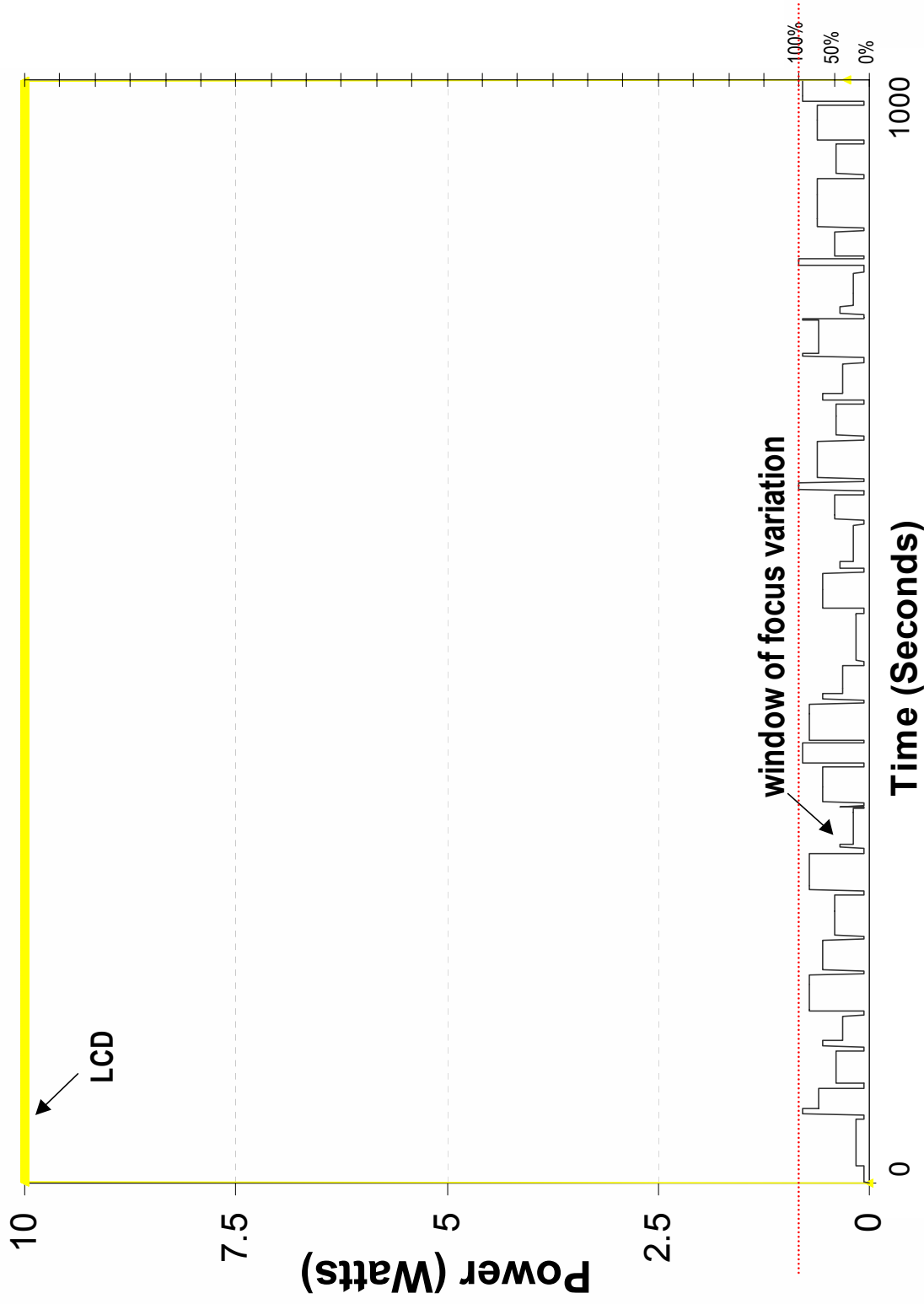
Pixel Power Value:

$$P_{\text{red}} = 4.3 \mu\text{W}, \quad P_{\text{green}} = 2.3 \mu\text{W}, \quad P_{\text{blue}} = 4.3 \mu\text{W}$$

Energy Adaptive Display

Power Benefits

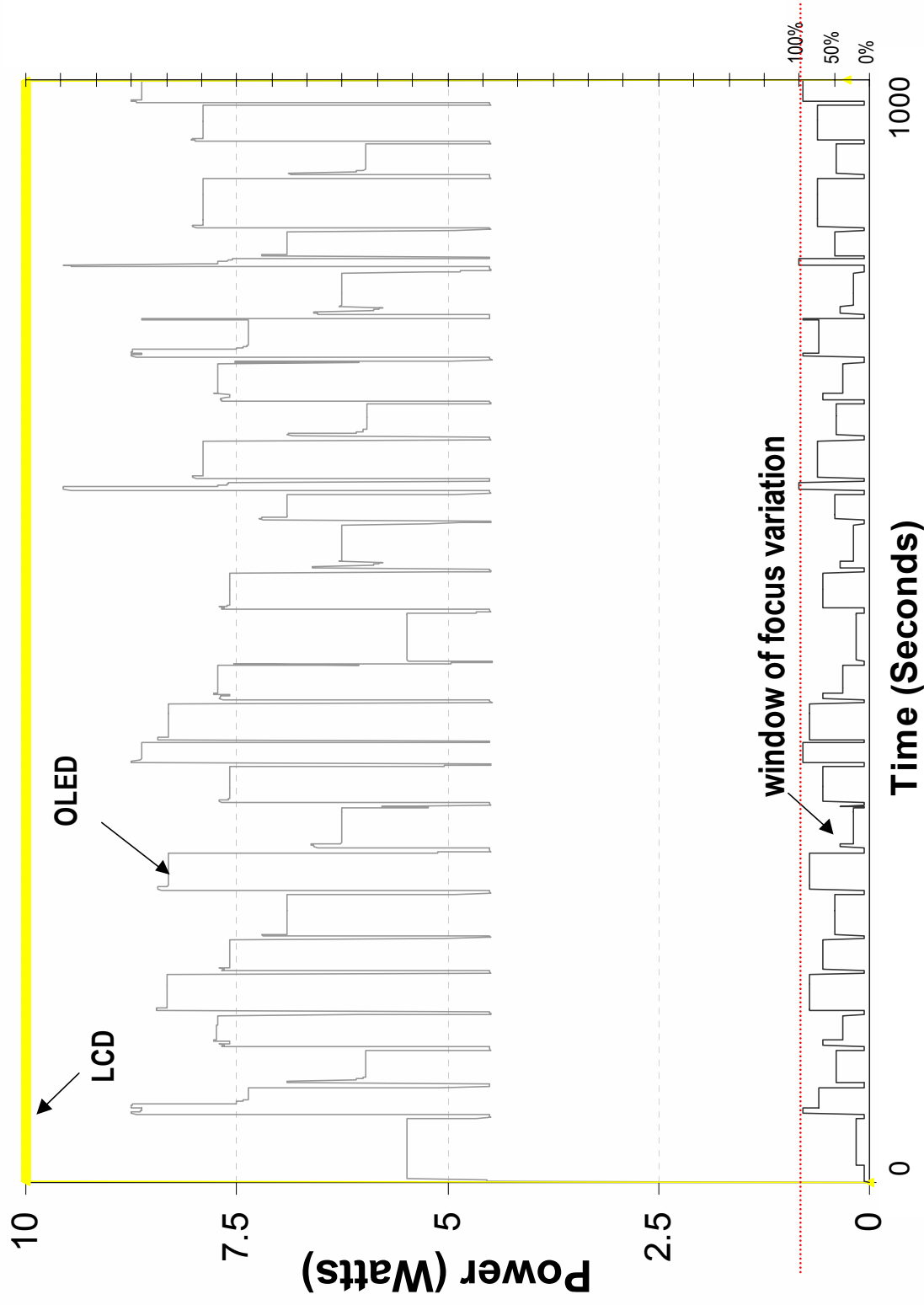
Power variation over time



Energy Adaptive Display

Power Benefits

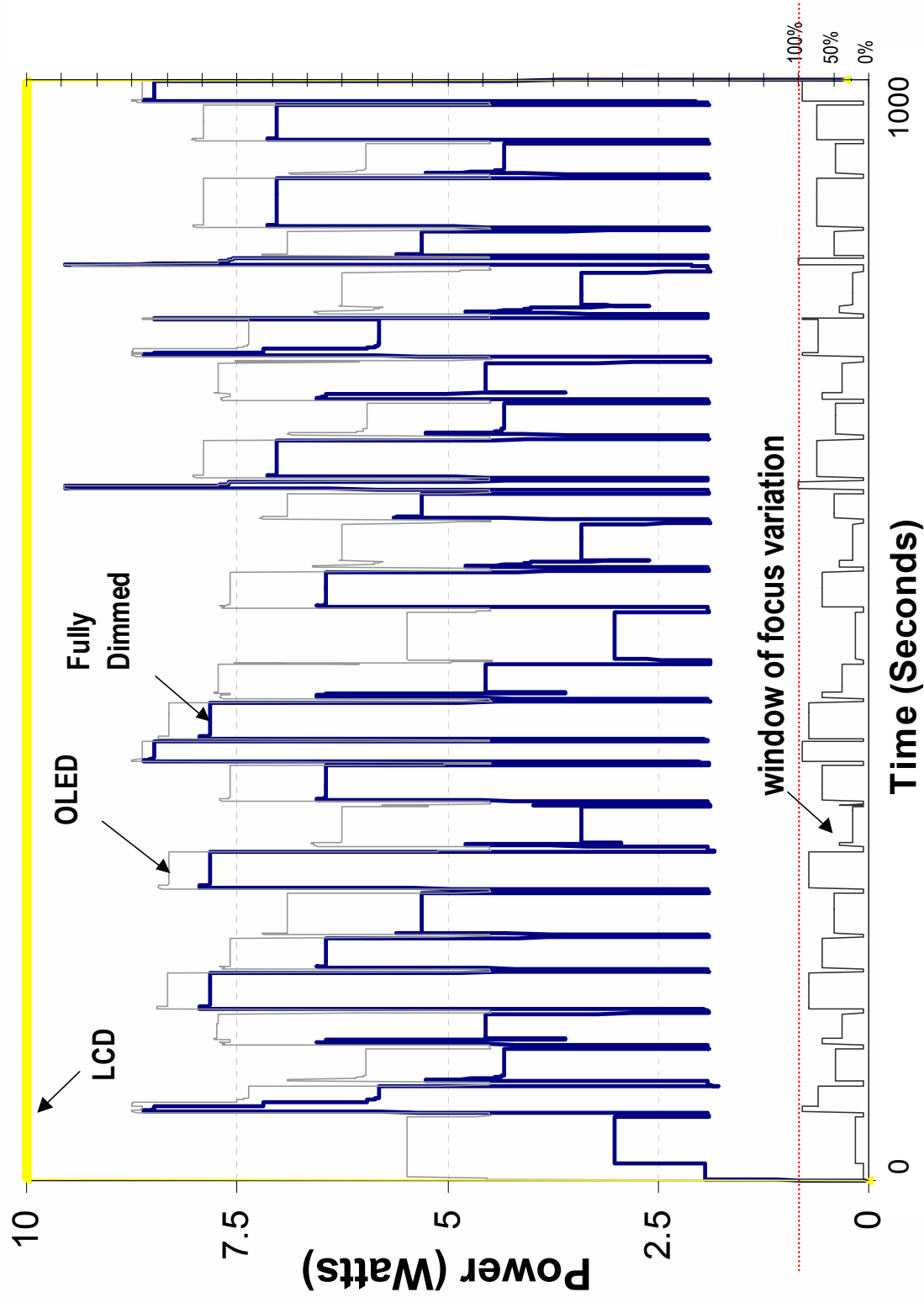
Power variation over time



Energy Adaptive Display

Power Benefits

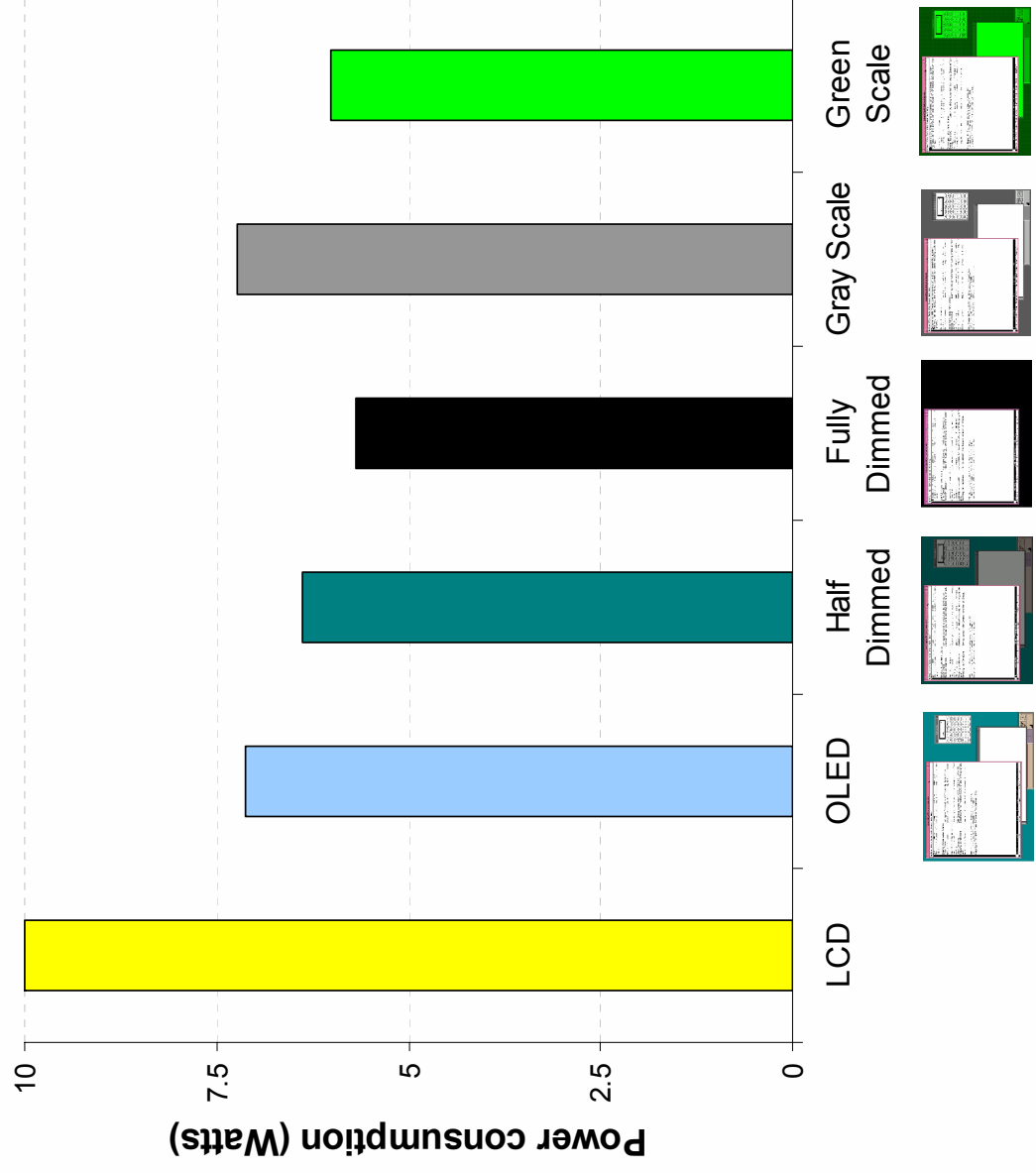
Power variation over time



Energy Adaptive Display

Power Benefits

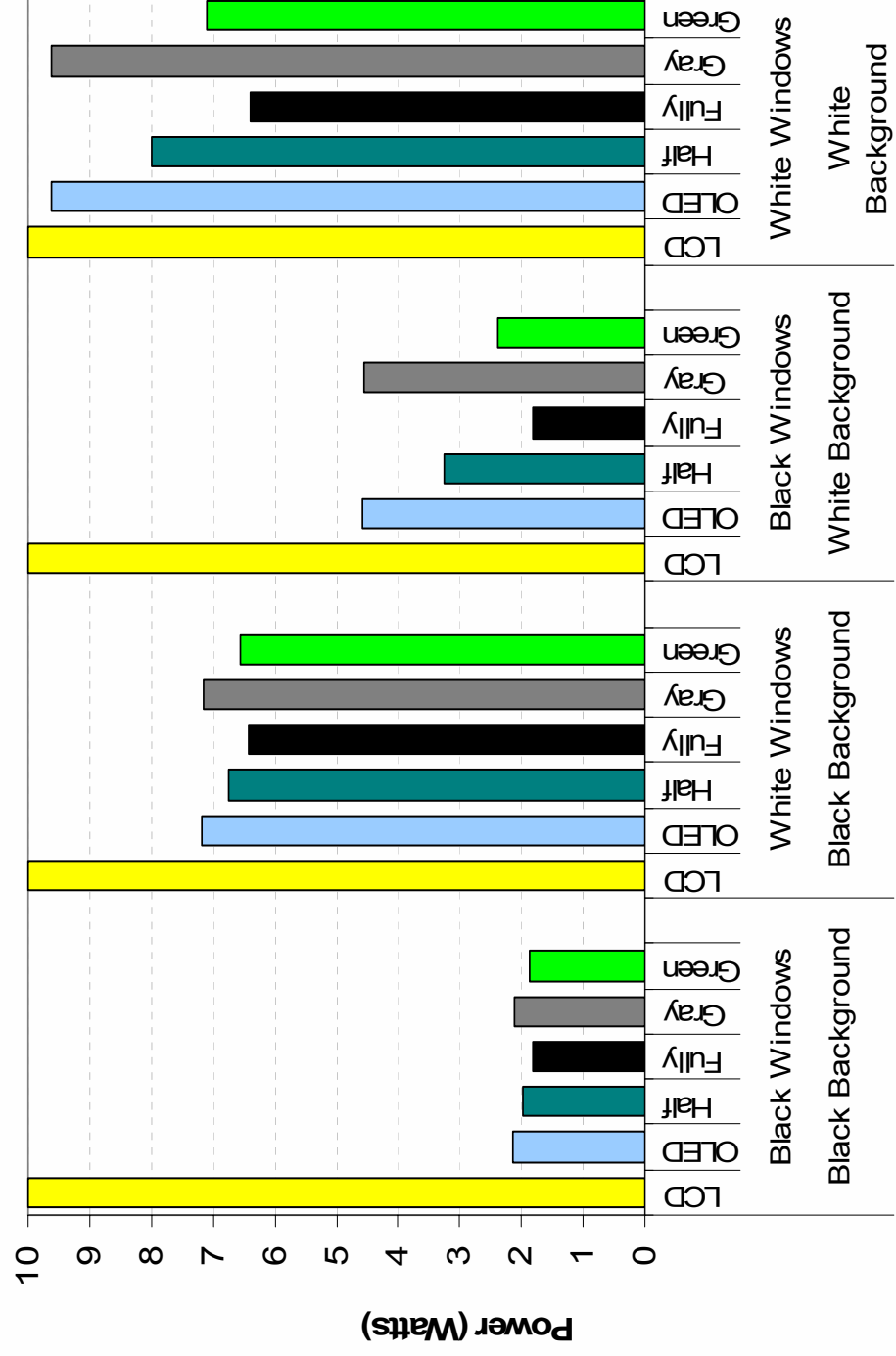
Power benefits analysis



Energy Adaptive Display

Power Benefits

Power benefits analysis (cont.)



Sensitivity of benefits to different background and window colors

Discussion

Hardware adaptability

- Emissive displays
- Hybrid technologies
- Multi-modal configuration
- Other output modes

Discussion



Default configuration



Hierarchy of windows



Other user interfaces

Software adaptability

- “Flashlight” or “headlight” cursor
- “Sticky lamps” on desktop
- Application-specific dimming
- Gradual fade in brightness, etc.

Conclusions

Identify mismatch of user needs and display properties

Conclusions

Propose energy-adaptive UI design for future displays

Indicate 40% power benefits on display subsystem

Future Work:

- Identify more user focus indicators
- Evaluate different energy-aware user interfaces

Related work

Choi, et.al. [1]

- Hardware power consumption of handheld devices
- Vary refresh rate, color depth, backlight luminance

Kamijoh [4] on IBM wristwatch Linux

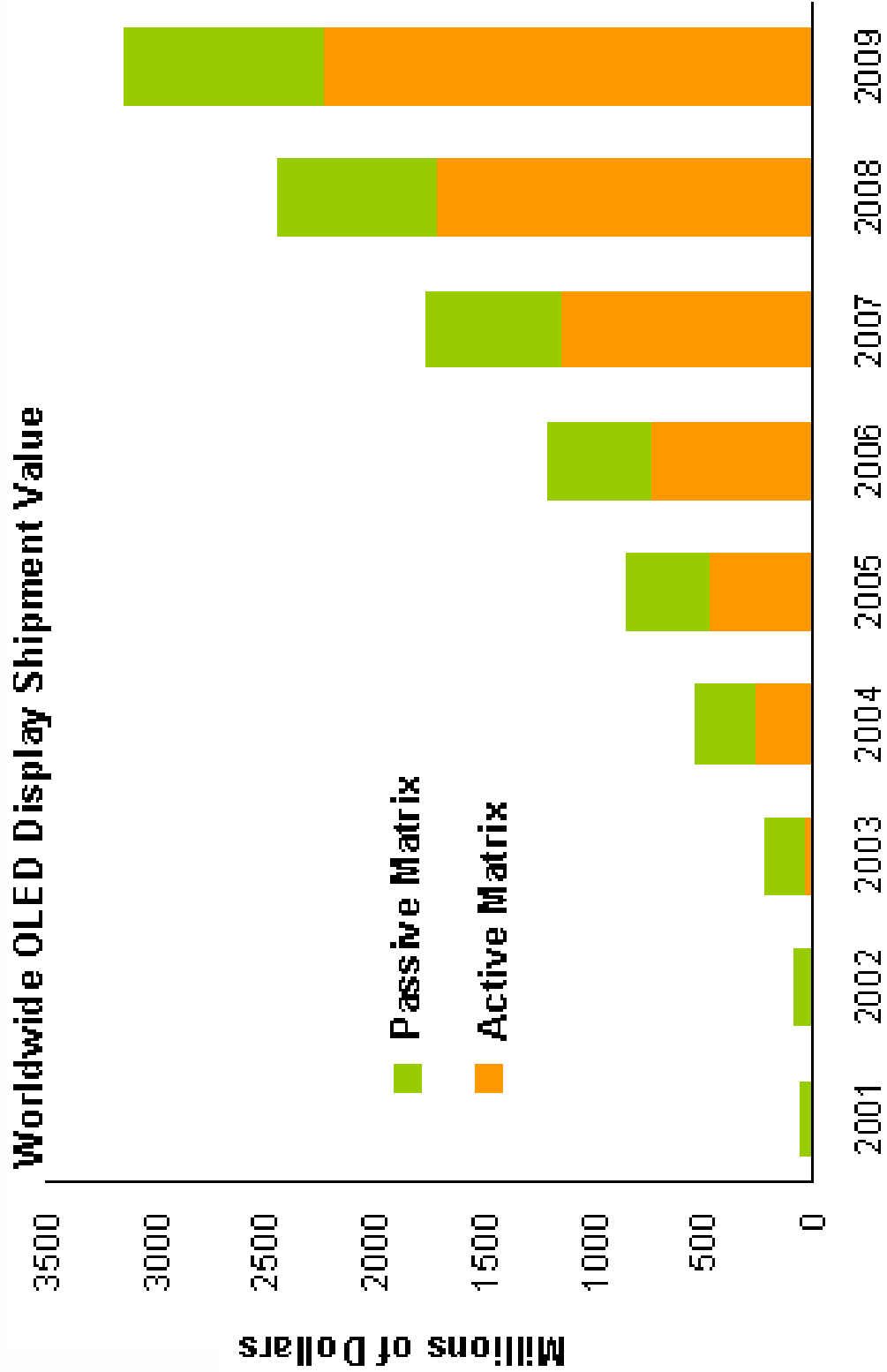
- Hardware-level tradeoffs and kernel optimization
- Use various standby and idle configurations

Flinn and Satyanarayan [2]

- Energy benefit from reduced computation (lower fidelity)
- “Zoned backlighting”

OLED Market Timeline

[2003, Stanford Resources]

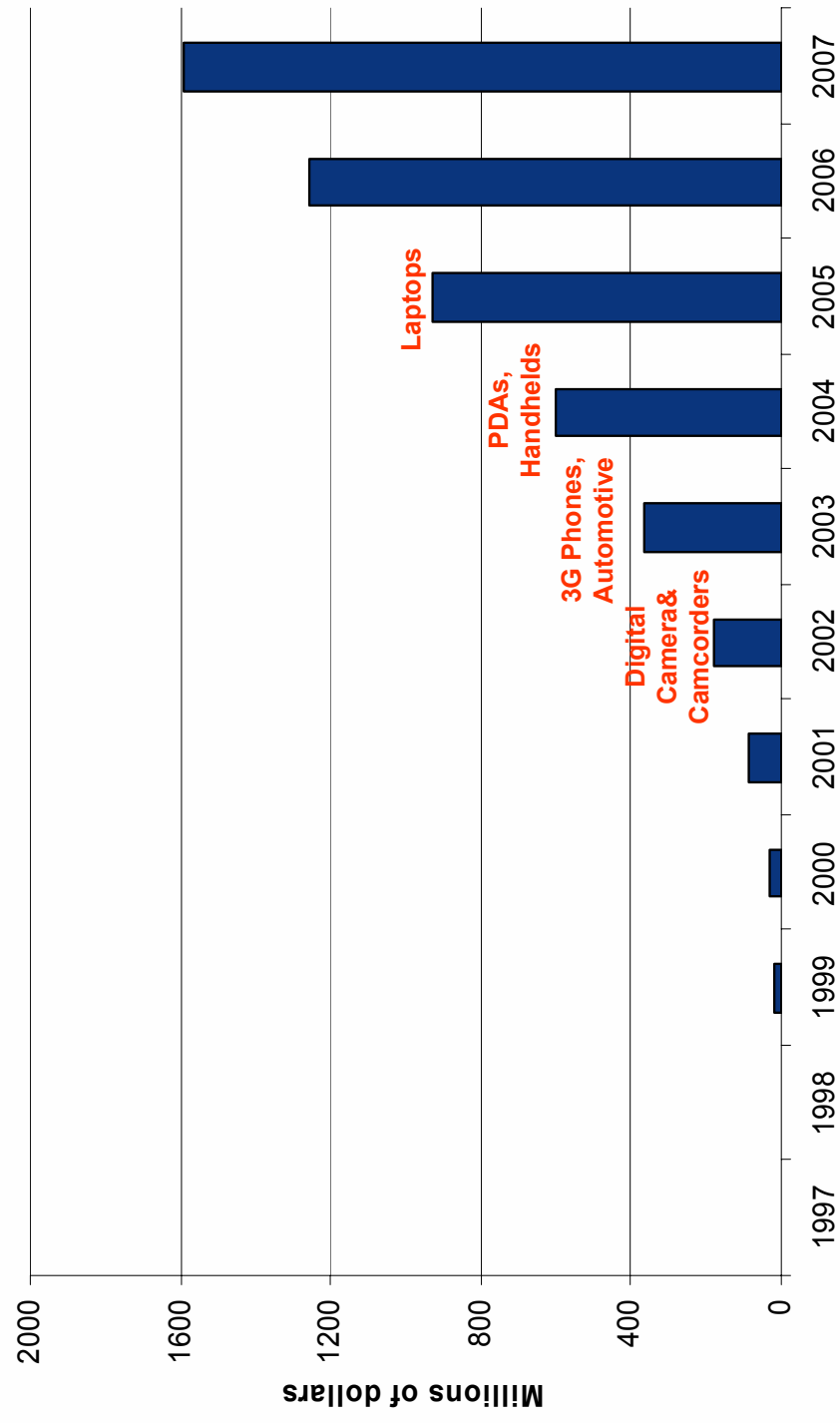


Source – iSuppli/Stanford Resources

OLED Market Timeline

[2001, Stanford Resources]

OLED market value (\$ Millions)
(all applications, world market, all drive types)



Screen usage by application

User Study

Active area (window of focus) is 0-25% (23% of the samples)
20% Task Bar, 15% Program Manager, 5% Xterm, 60% misc windows
Active area (window of focus) is 25-50% (22% of the samples)
19% Xterm, 18% message composition, 6% Internet Explorer, 57% misc windows
Active area (window of focus) is 50-75% (28% of the samples)
33% Internet Explorer, 24% mail composition and reading, 57% misc windows
Active area (window of focus) is 75-100% (27% of the samples)
21% mail composition and reading, 20% Internet Explorer, 7% Excel, 52% misc windows

Thank you!

For more information:

Annie Lu Luo

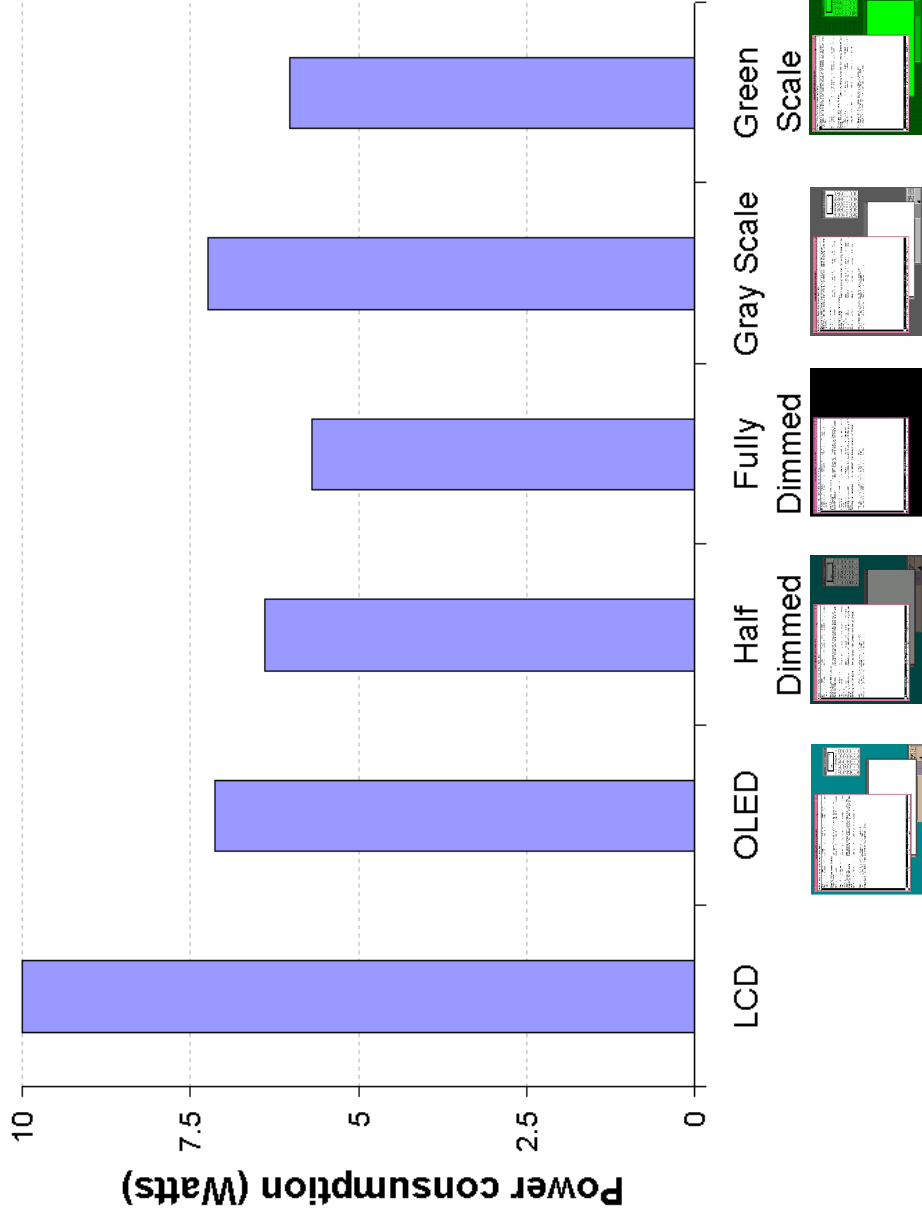
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Energy Adaptive Display

Energy Benefits

Power benefits analysis

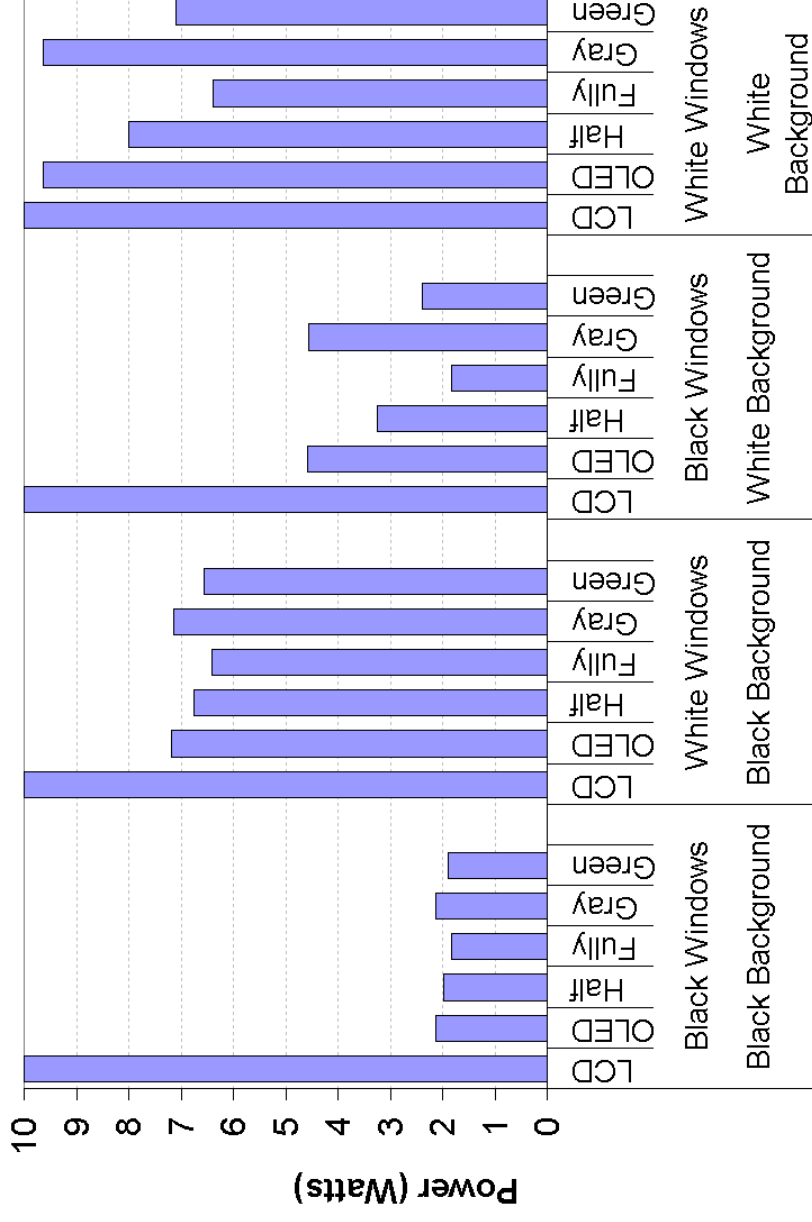


Power benefits from energy-adaptive display designs

Energy Adaptive Display

Energy Benefits

Power benefits analysis (cont.)



Sensitivity of benefits to different background and window colors

