Energy-Adaptive Display System Designs for Future Mobile Environments

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Energy Adaptive Display

Motivation

Motivation

Displays consume significant power in mobile systems

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

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

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Contribution

Contributions

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

Energy Adaptive Display

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

Energy Adaptive Display

User Study

Methodology for the 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

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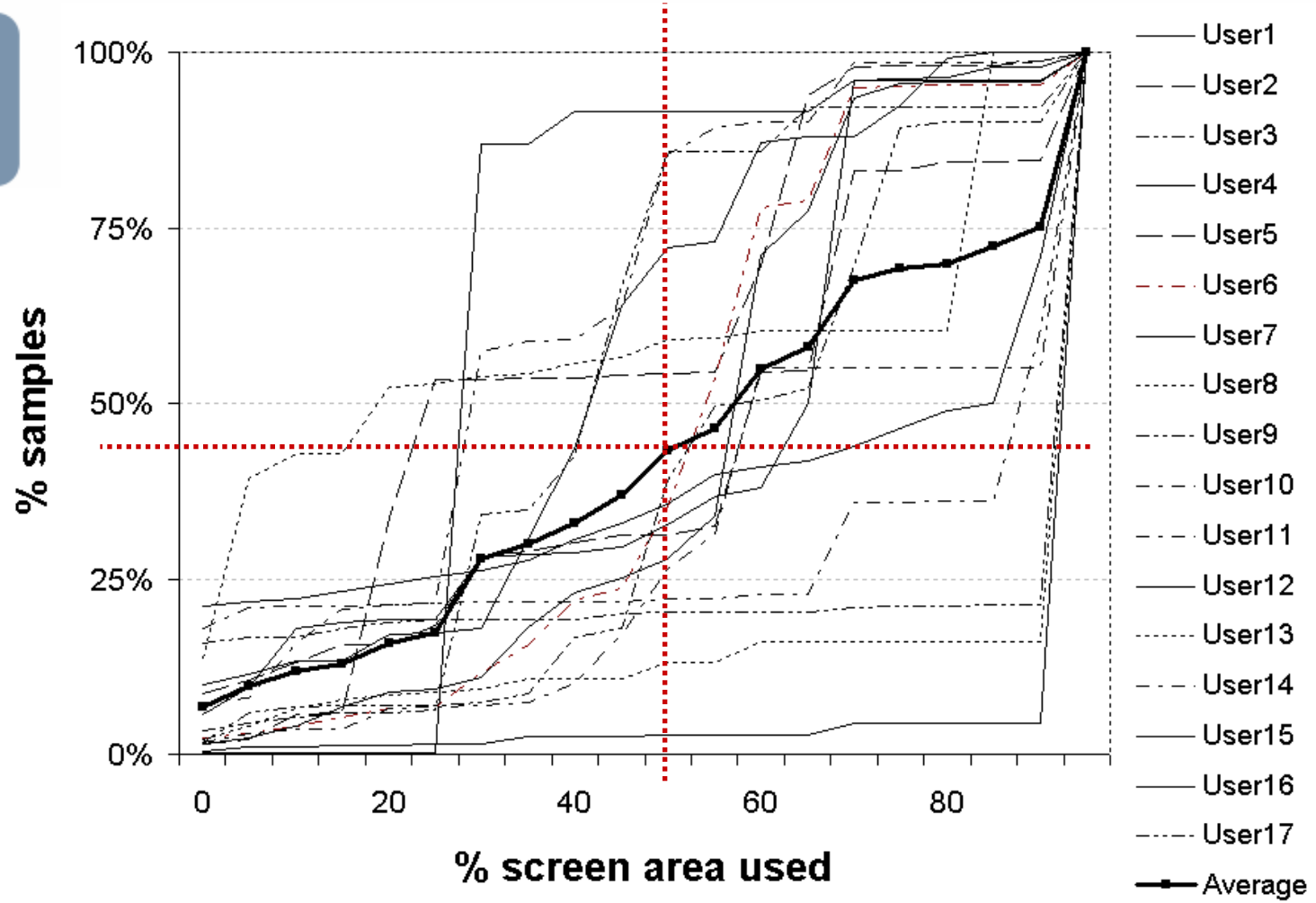
User Study

User study results



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User Study

User study results (cont.)

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!

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Energy Adaptive Display

Hardware Support

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

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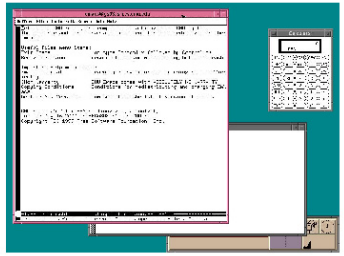
Software Support

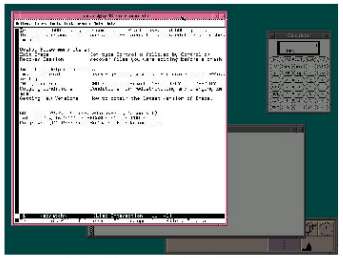
System design – software support

User Interface optimization: "Dark Windows"

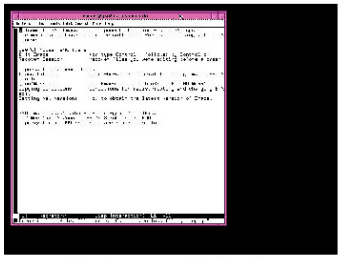
- Automatic power-aware adaptation of brightness and color
- Not modified: window-of-focus
- Modified: remaining screen areas



Original Interface

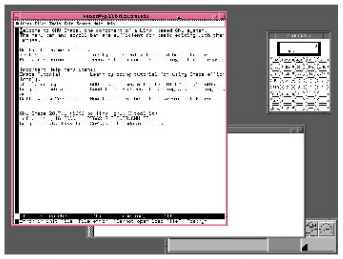


Background half dim

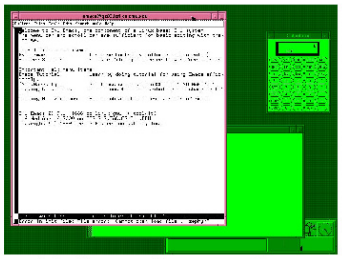


Background fully dim

Dark Windows – Brightness Control



Background grayscale



Background greenscale

Dark Windows – Color Control

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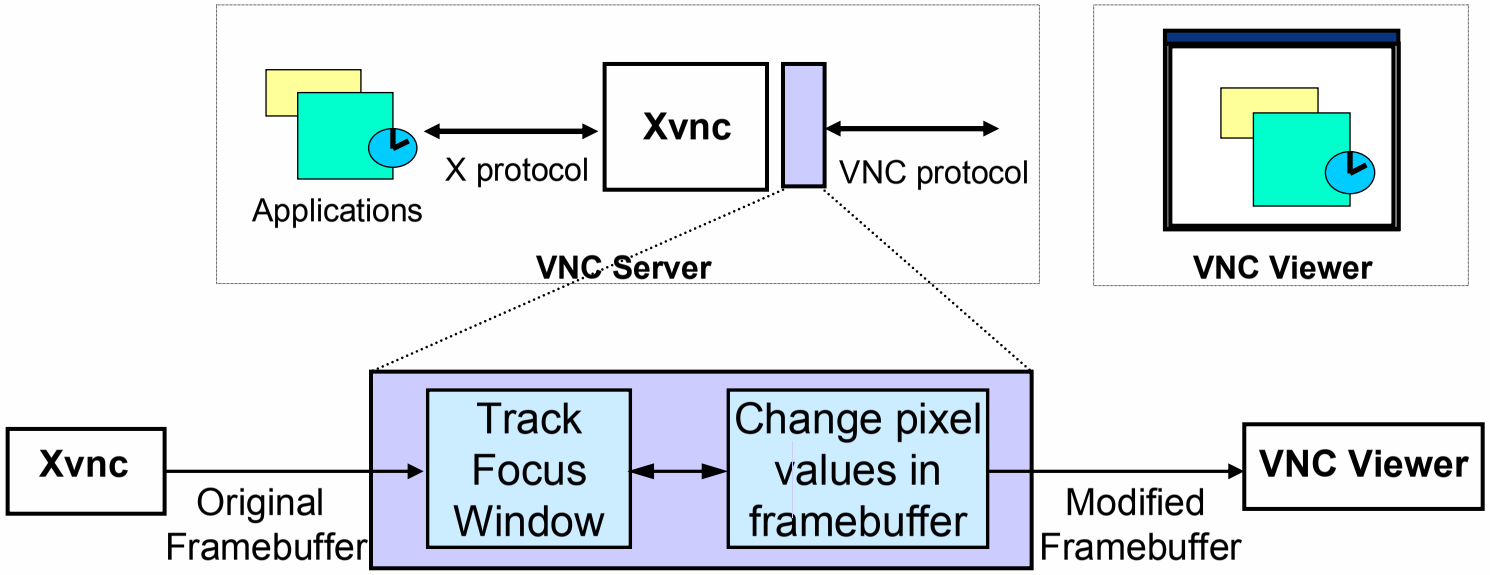
Prototype

Prototyping the user interface

Based on X Window System under Linux

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



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Evaluation Methodology

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

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Power Model

Power model

15” OLED displays not available

Representative software power model:

- OLED datasheets
- Display experts

Display Power = $P_{controller} + P_{driver}$ + **Panel Power**

Panel Power = **Pixel Array Power**

$$= \sum_{all\_pixel} (P_{red} \times pixel_R + P_{green} \times pixel_G + P_{blue} \times pixel_B)$$

Pixel Power Value:

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

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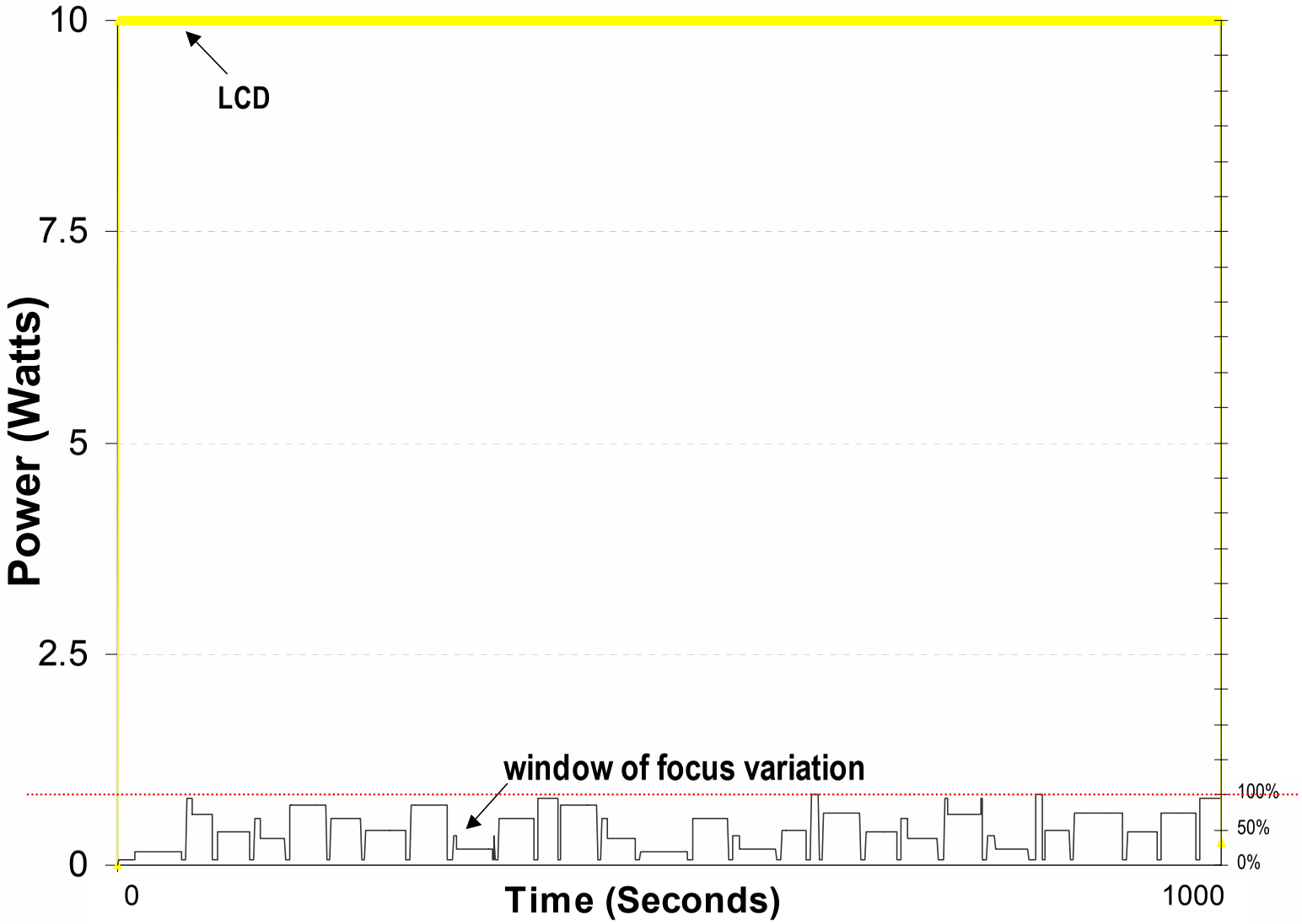
Power Benefits

Power variation over time



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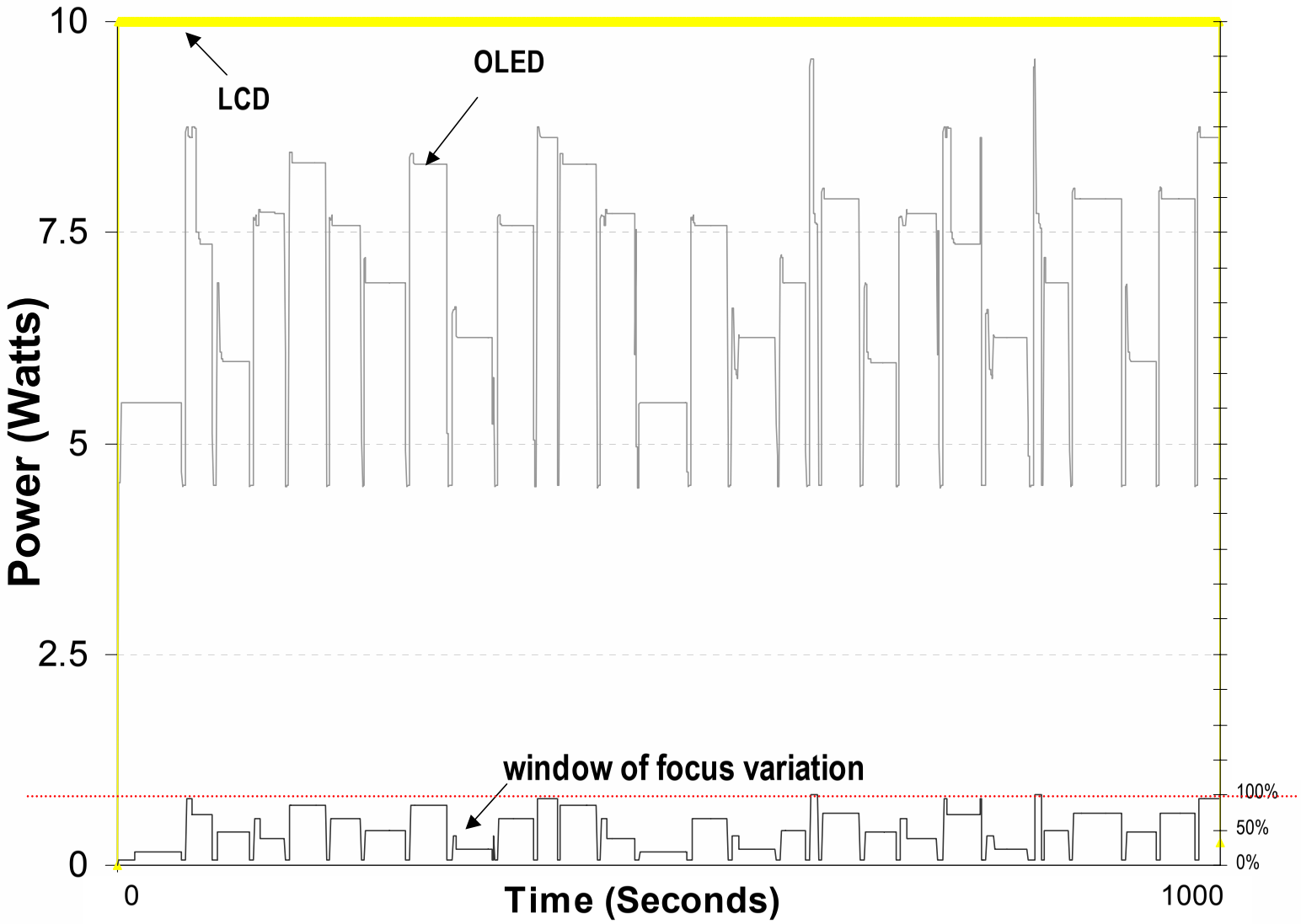
Power Benefits

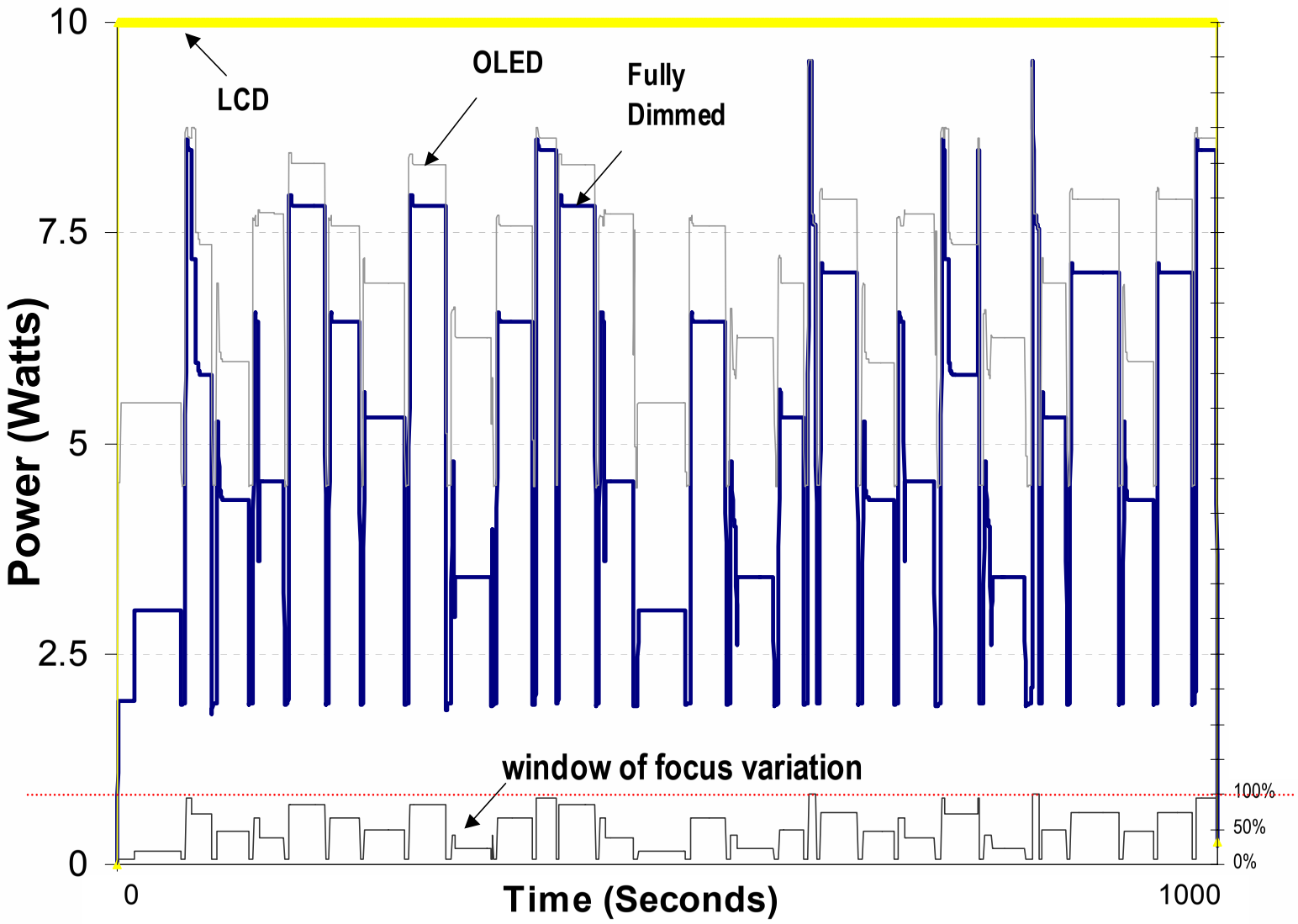
Power variation over time



Energy Adaptive Display

Power Benefits

Power variation over time



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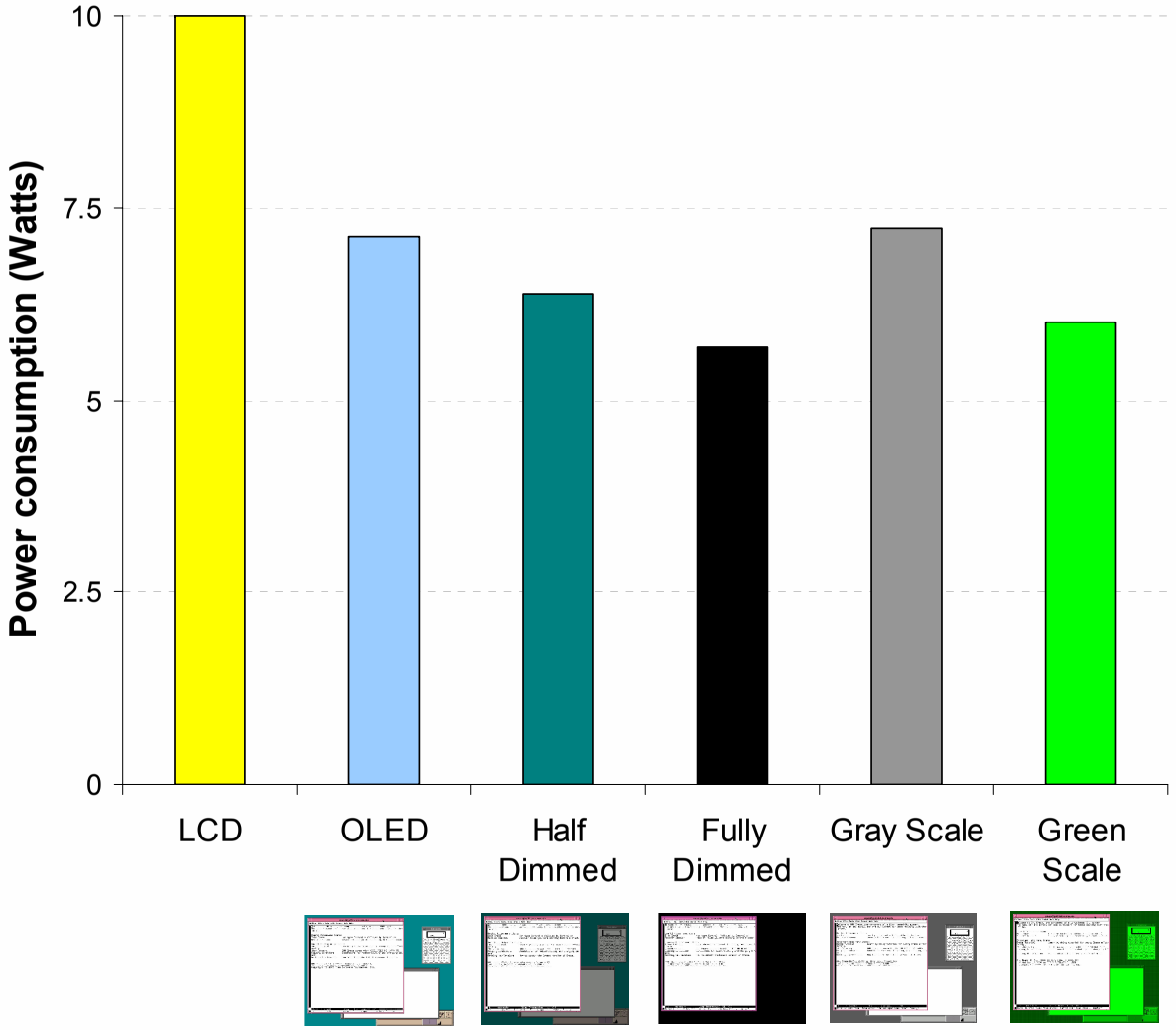
Power Benefits

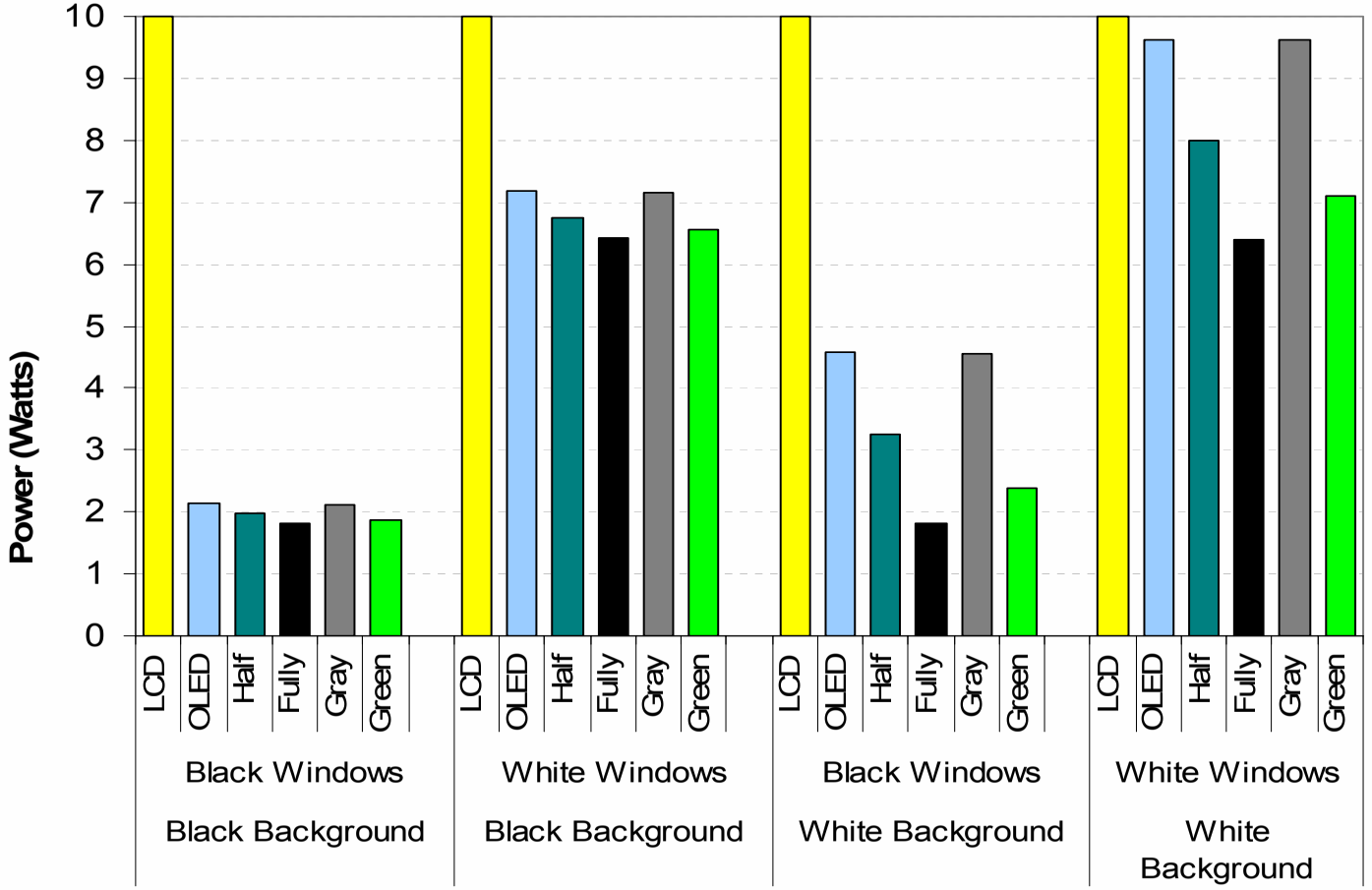
Power benefits analysis



Energy Adaptive Display

Power Benefits

Power benefits analysis (cont.)



Sensitivity of benefits to different background and window colors

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Discussion

Discussion

Hardware adaptability

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

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.

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Conclusions

Conclusions

Identify mismatch of user needs and display properties

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

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Related Work

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”

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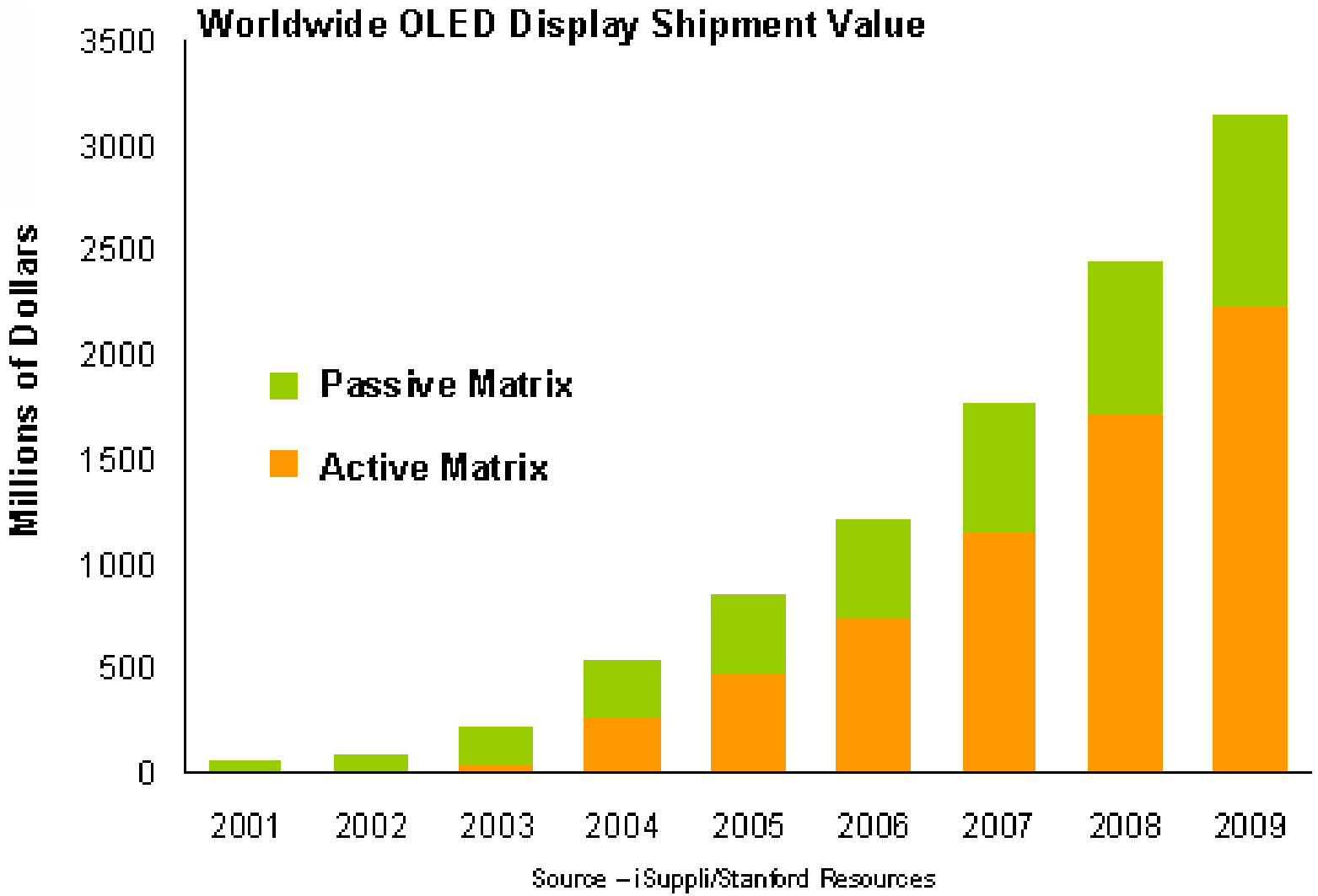
Appendix

OLED Market Timeline [2003, Stanford Resources]



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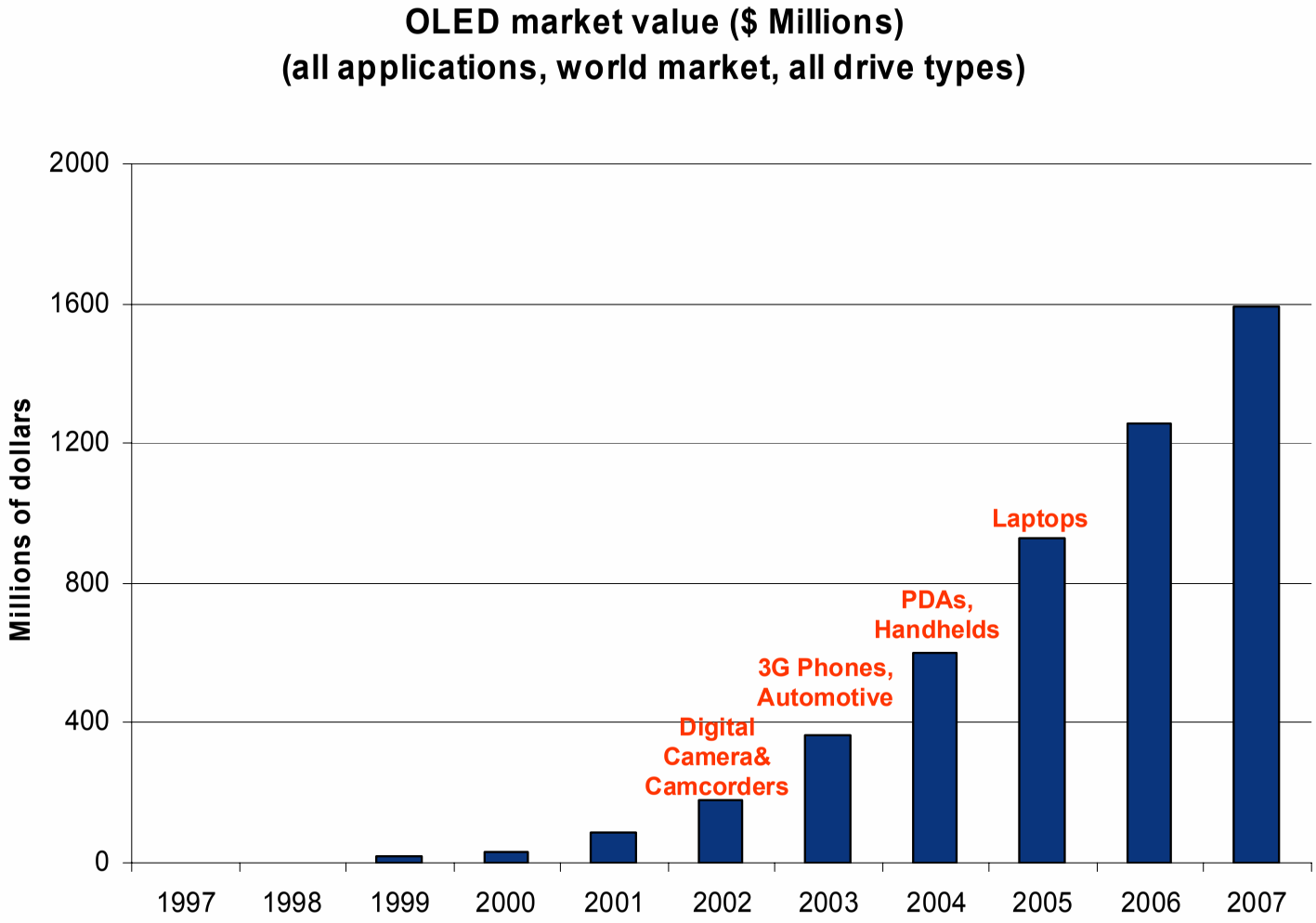
Appendix

OLED Market Timeline [2001, Stanford Resources]



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User Study

Screen usage by application

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

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Thank you!

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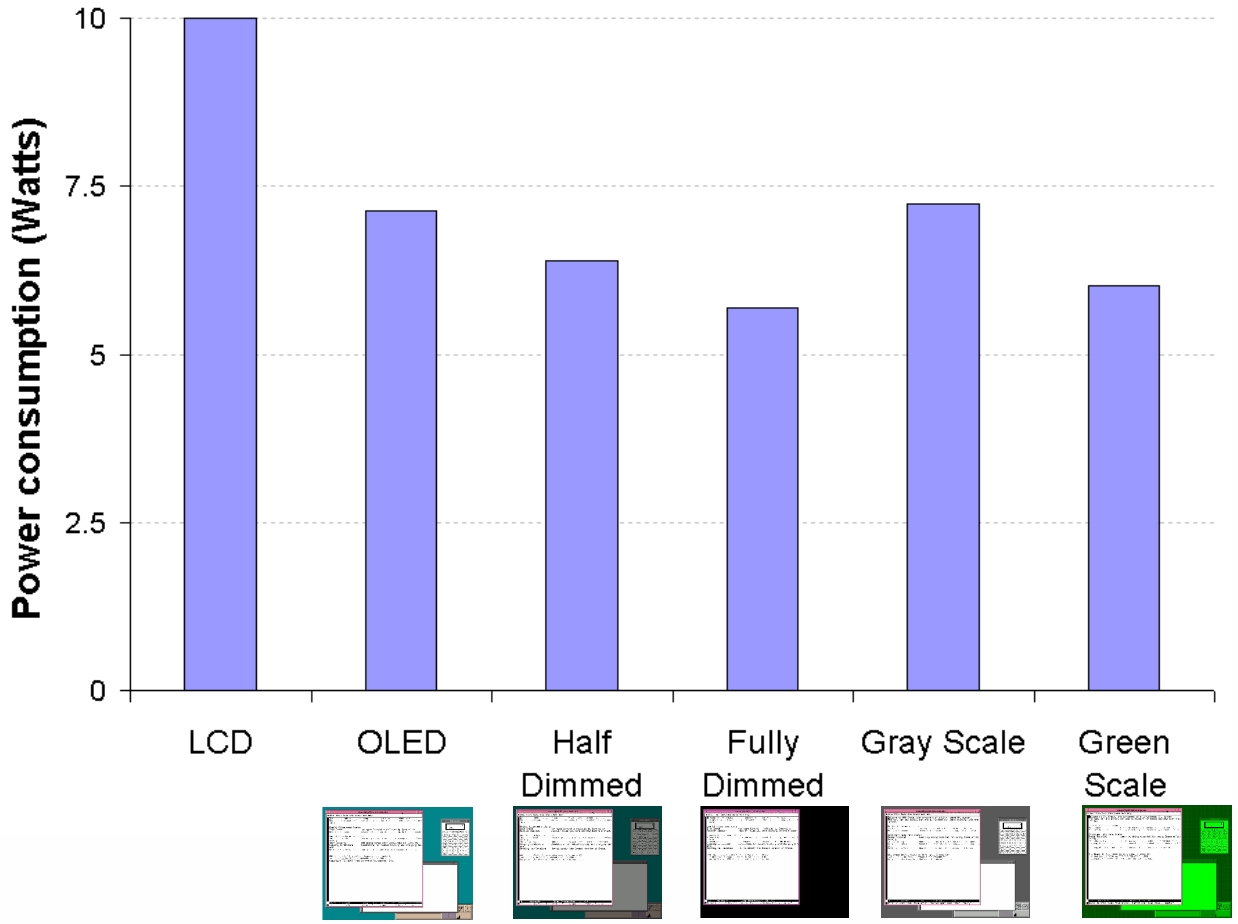
Energy Benefits

Power benefits analysis



Power benefits from energy-adaptive display designs

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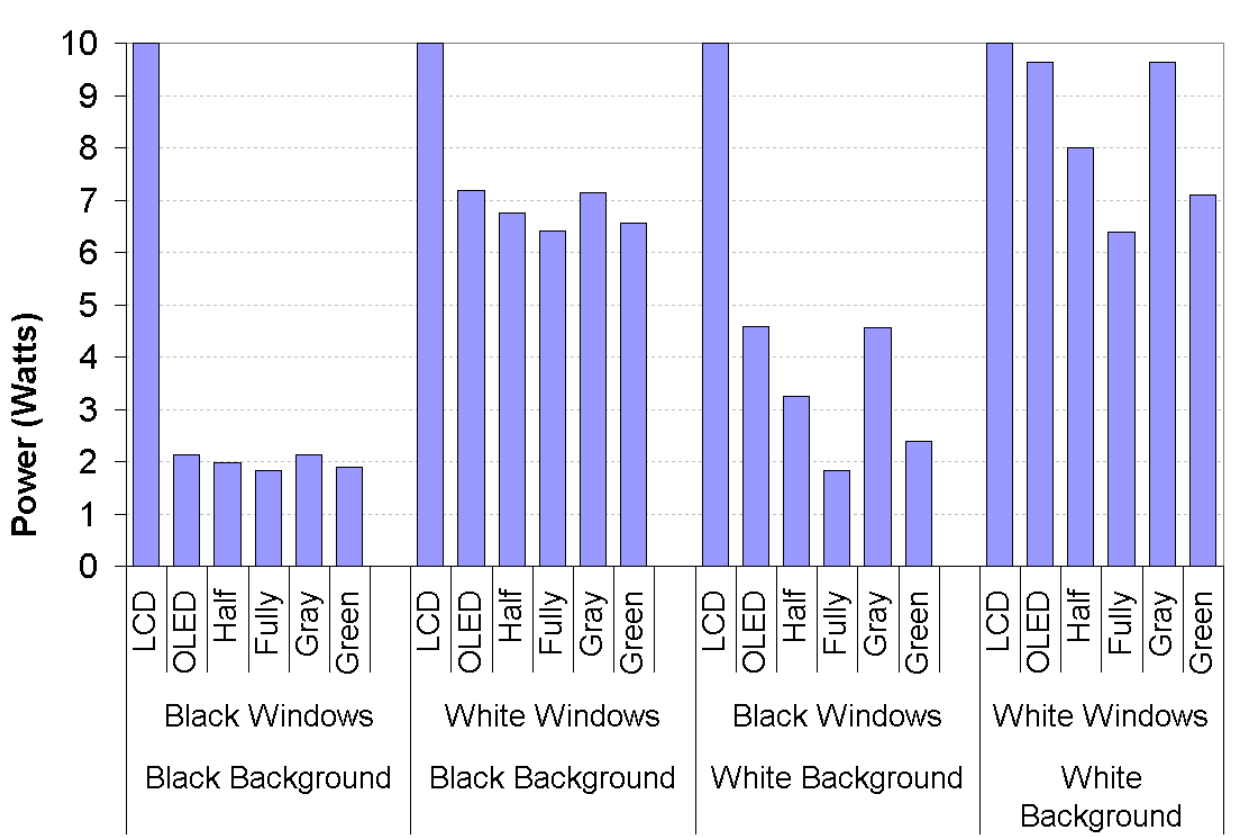
Energy Benefits

Power benefits analysis (cont.)



Sensitivity of benefits to different background and window colors

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Appendix

Power benefit analysis