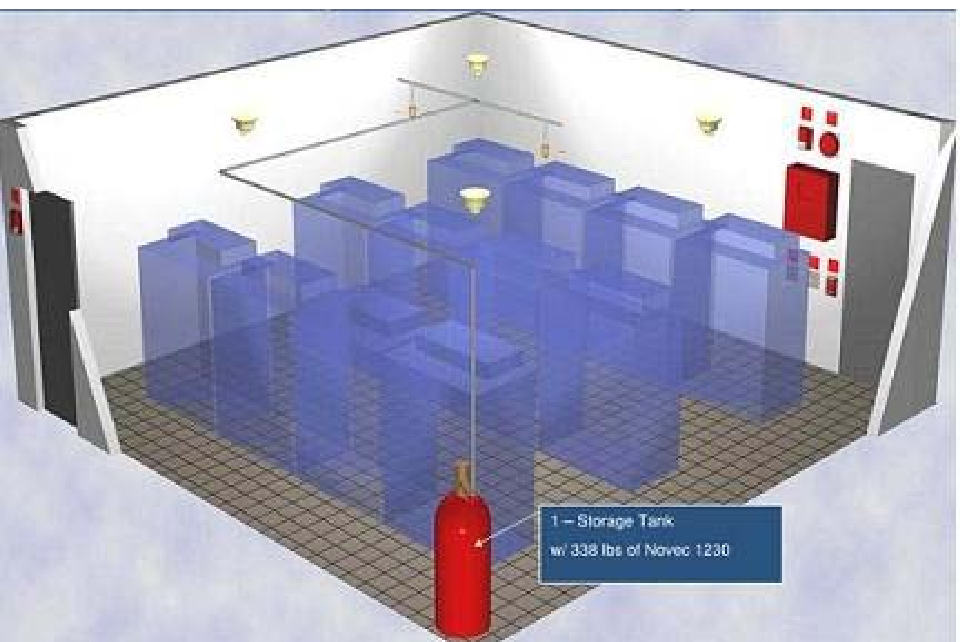
MODELING THE PERFORMANCE OF FIRE PROTECTION SYSTEMS IN MODERN DATA CENTERS



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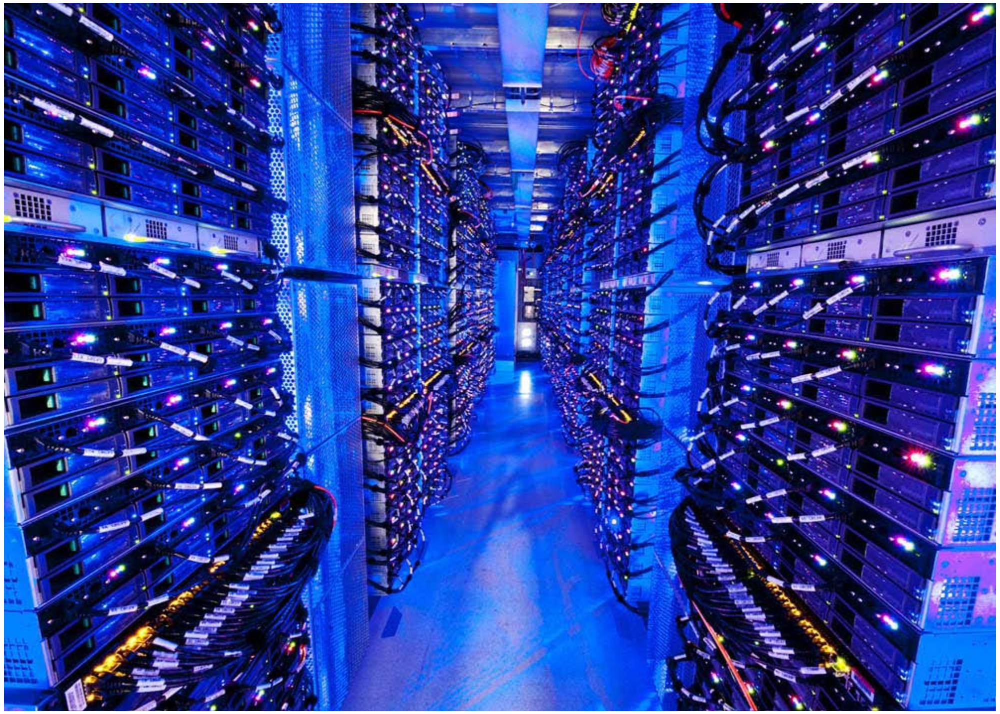
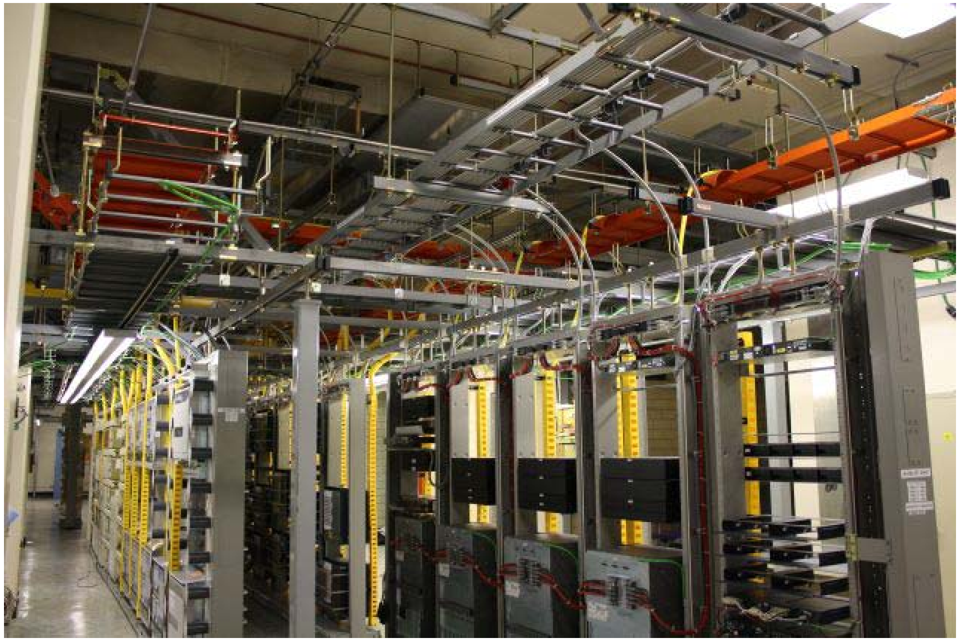
Data Centers

- Society increasingly requires instantaneous access to vast amounts of data
- Backup operations using manual procedures are no longer suitable
- Cloud computing places even more emphasis on uninterrupted data access
- Fault tolerant systems utilizing three independent copies are becoming the standard
  - One copy in a different city
  - One copy on a different continent



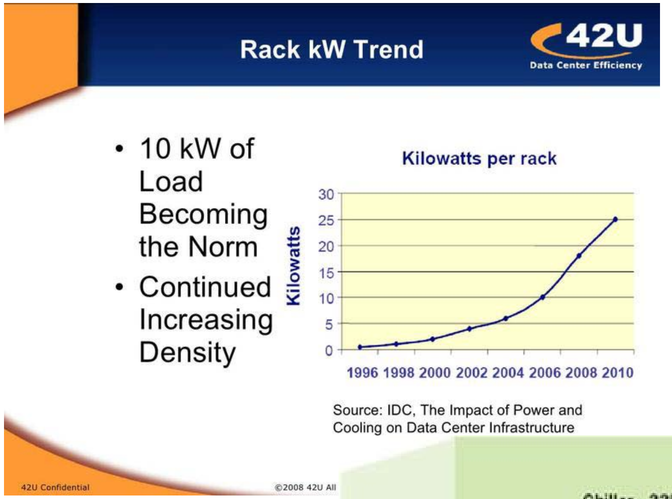
Telecommunications Facilities

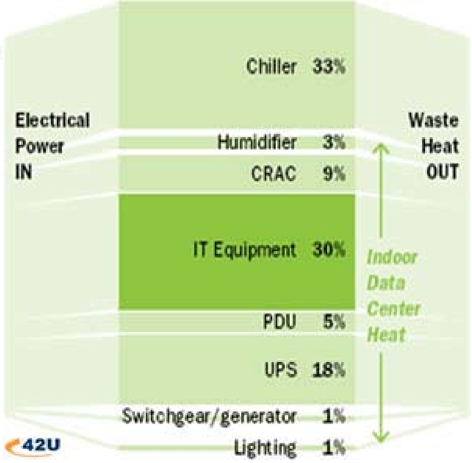
- Replace the traditional Central Office
- Route calls and data, managing transitions between pathways (fiber, cellular, microwave, satellite)
- Highly automated nodes in a fault tolerant system that can bypass any problem node



Common Issues

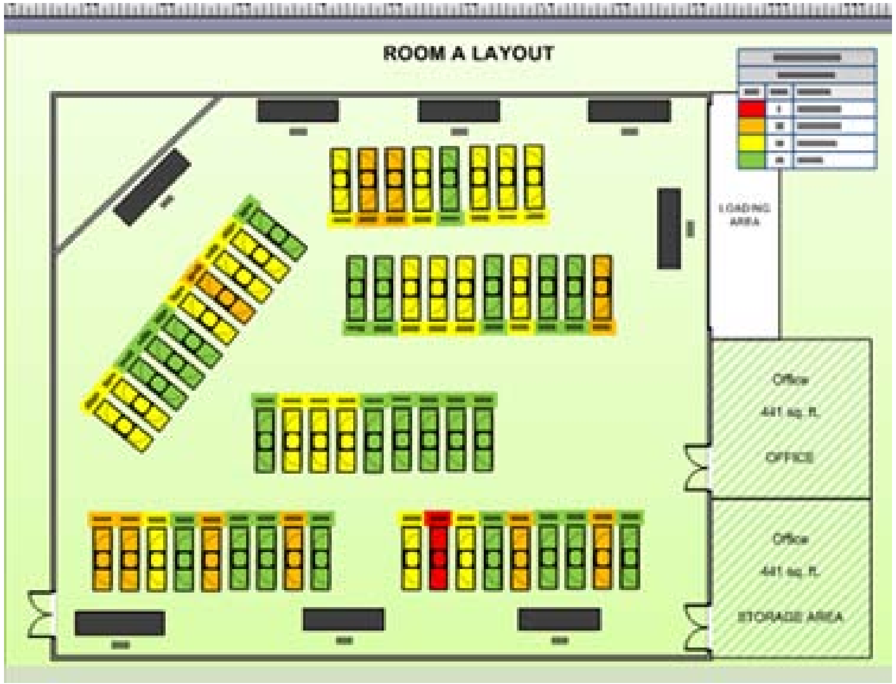
- Increasing power densities as more equipment is packed into the same space
- Sustainability demands for lower power use and more efficient cooling
- Increasing demands for uninterruptable power solutions with low carbon footprint
- Expansion of critical services such as cloud computing
  - You will no longer have physical possession of any of your digital content





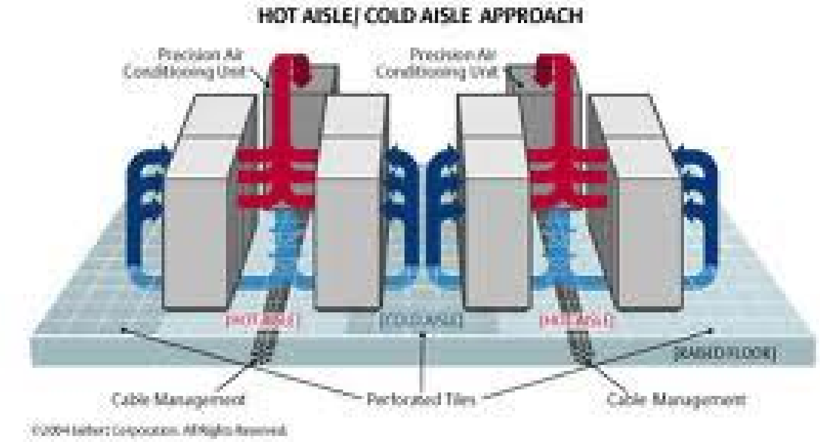
Equipment Configurations

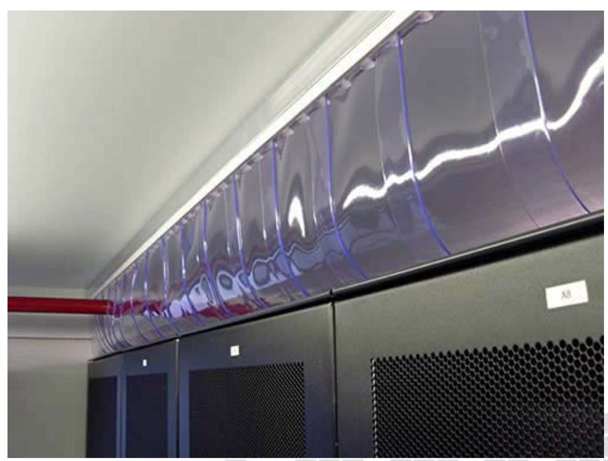
- Vast spaces filled with rows of racks
  - Power supplies (UPS) at the bottom for stability
  - Stacked server units to the top with data cables at rear
  - Cool air in bottom and warm out top
  - Blanks needed in empty spaces to guide airflow
- CRAC units around periphery circulate air in one of several ways
- Associated office space
- May or may not be raised floor or ceiling plenum



Cooling Air Containment

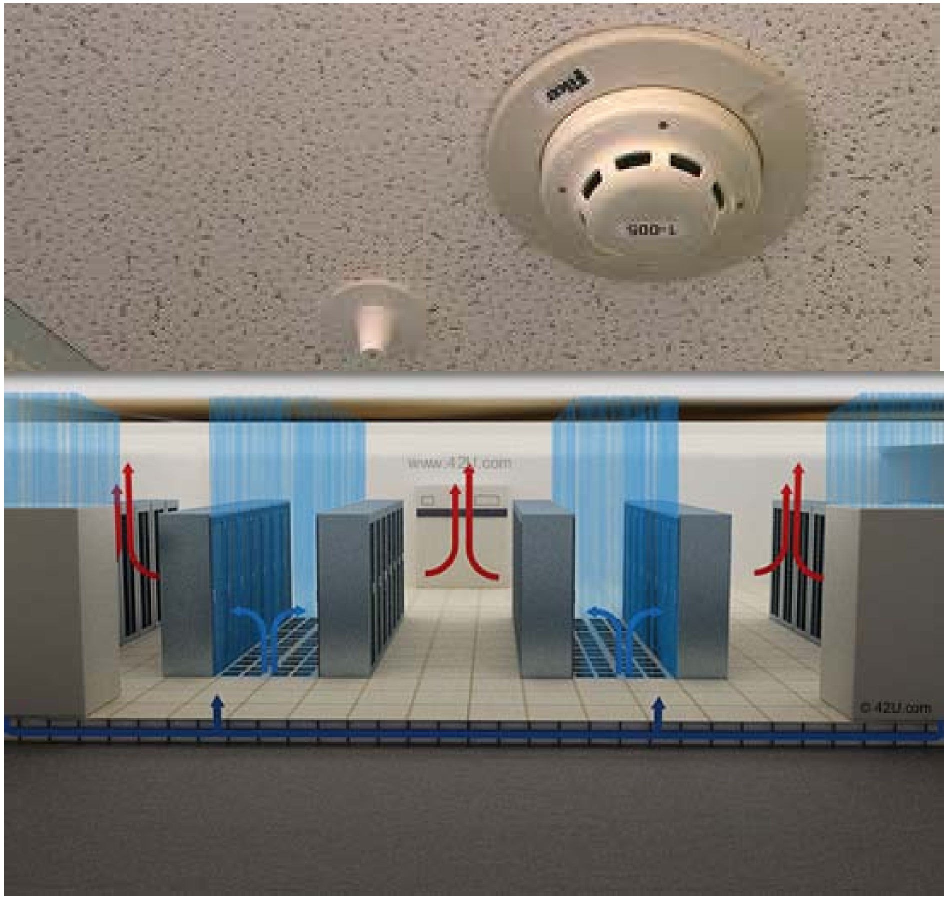
- Cooling the equipment vs cooling the space
- Increasing return air temperatures increases cooling efficiency
  - Curtains
  - Hot aisle Cold aisle
  - Hot collar





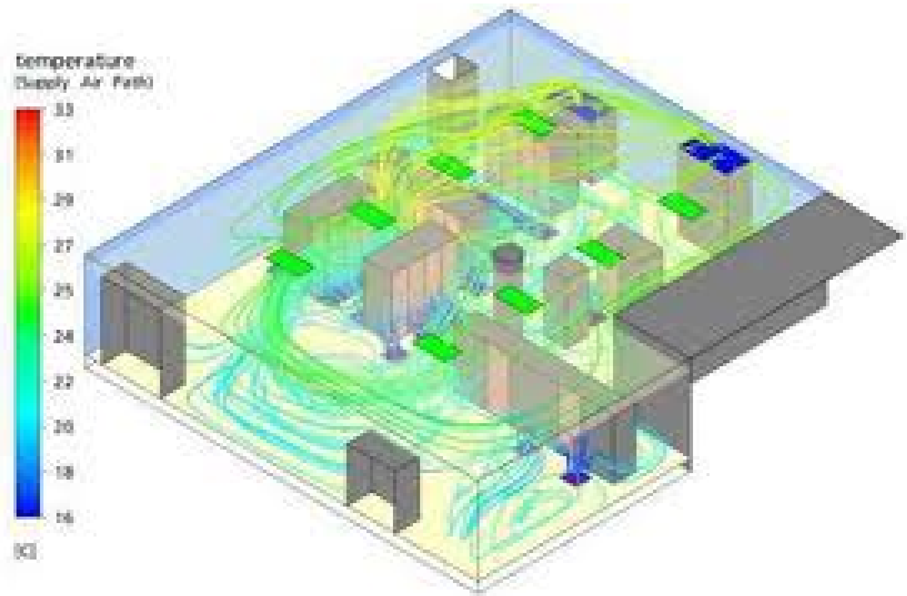
Fire Protection

- Open area smoke detectors including aspirated
  - High airflow guidance in NFPA 72 is sparse
  - 1990 AT&T tests in CO showed good performance by aspirated
- Clean agent suppression protecting contents and sprinklers protecting building
- Airflow directing curtains can block smoke from detectors and agent from equipment



Fluid Dynamics Models

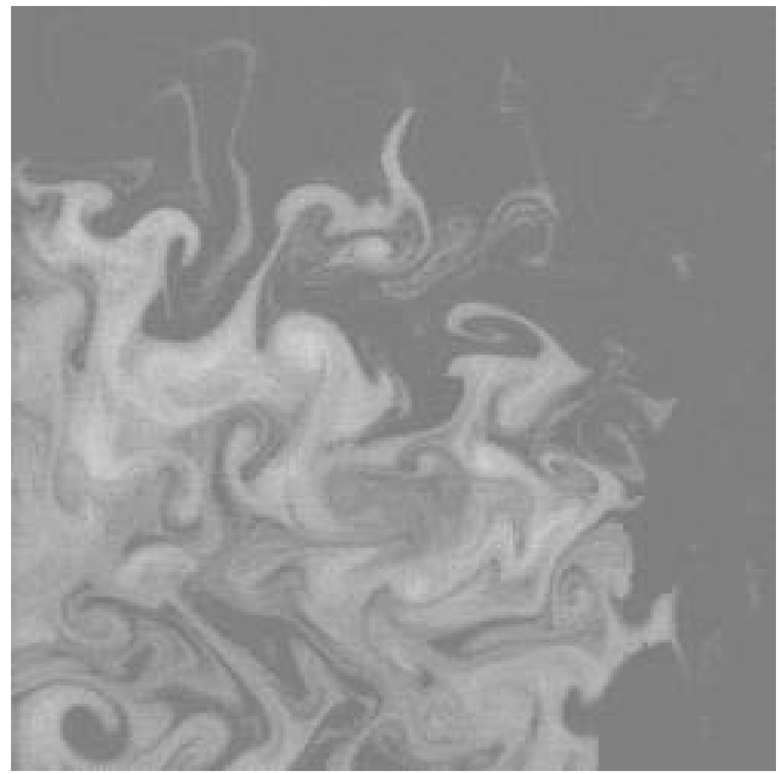
- CFD models have been used to visualize airflow and cooling system performance
- Can CFD models be used to site detectors for optimum performance for specific design fires?



Fluid Dynamics Models

Overview

- Solve *Navier-Stokes Equations* for fluid flow (detailed velocity field)
- Different approaches to **turbulence**
  - Reynolds Averaged (RANS)
  - (*κ*-*ε*) (most fire models)
  - Large Eddy Simulation (LES)



Selecting a Model for Data Centers

- RANS averaging smears details of the flow needed for detector response prediction
- (κ-ε) models require values for κ and ε to be selected by the user
- LES models predict flow from 1st principles but require significant computing resources
  - IPHONE has 36 times the computing power of a Cray 1
  - Inexpensive LINIX clusters can be assembled from PCs (shown:14 node 21 processor cluster at Yale Engineering)

FDS

Detector Response Prediction

- FDS/SMOKEview are available at no cost from NIST
- Developers will collaborate to extend model at no cost as long as extension is publically available
- FDS is a fire model that can account for combustion, buoyant flows and heat transfer not addressed in models used only to predict flows
- FDS predicts smoke detector activation from smoke obscuration (mass concentration), local velocity and entry lag (Heskestad)
- Published validation studies of smoke detector response prediction are available

- W. Zhang, S.M. Olenick, M.S. Klassen, D.J. Carpenter, R.J. Roby, and J.L. Torero. A smoke detector activation algorithm for large eddy simulation fire modeling. Fire Safety Journal, 43:96–107, 2008.
- D.R. Brammer. A Comparison between Predicted and Actual Behaviour of Domestic Smoke Detectors in a Realistic House Fire. Master's thesis, University of Canterbury, Christchurch, New Zealand, 2002.
- V. D'Souza, J.A. Sutula, S.M. Olenick, W. Zhang, and R.J. Roby. Use of Fire Dynamics Simulator to Predict Smoke Detector Activation. In Proceedings of the 2001 Fall Technical Meeting, Eastern States Section, pages 175–178. Combustion Institute, Pittsburgh, Pennsylvania, December 2001.
- T. Cleary, M. Donnelly, G. Mulholland, and B. Farouk. Fire Detector Performance Predictions in a Simulated Multi-Room Configuration. In Proceedings of the 12th International Conference on Automatic Fire Detection (AUBE '01). National Institute of Standards and Technology, Gaithersburg, Maryland, March 2001. NIST SP 965.

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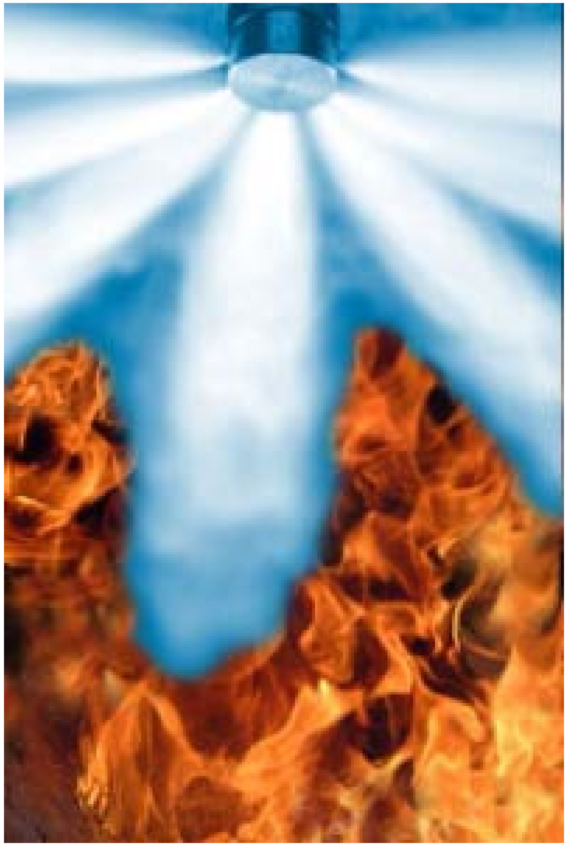
FDS

Gaseous Agent Concentration

- Smoke detector response is predicted by tracking soot mass from a point of combustion, carried in the flow to a point where a detector is located
- Detection occurs when the local soot mass concentration exceeds the concentration for activation
- Extinguishment is predicted by tracking agent mass from a point where a nozzle is located, carried in the flow to a point of combustion
- Extinguishment occurs when the local agent volume concentration exceeds the concentration for extinguishment
- THIS IS THE SAME CALCULATION; IF YOU CAN DO ONE, YOU CAN DO BOTH



Design Fire Scenarios

Electrical Fires in Digital Equipment

- Digital electronics operate at low voltage (1-5 vdc)
- High circuit densities and clock rates result in significant heat dissipation that can build if cooling is insufficient
- High voltage only present in UPS/power supply at rack bottom
  - Locating remotely would reduce fire risk but create issues for power losses
  - Operated from 240 vac and near capacity for efficiency
- Primary fuel is wire insulation which burns slowly but produces corrosive smoke

Design Fire Scenarios

Cable Tray Fires

- Cable tray fires extensively studied by the nuclear power industry following Browns Ferry fire
- CFAST and FDS have been validated by NRC for modeling cable tray fires
- Passive techniques utilized in nuclear plants to protect cables in trays are not applicable to data centers where wires are frequently changed
- Fire properties of cables needed for modeling are well documented

Design Fire Scenarios

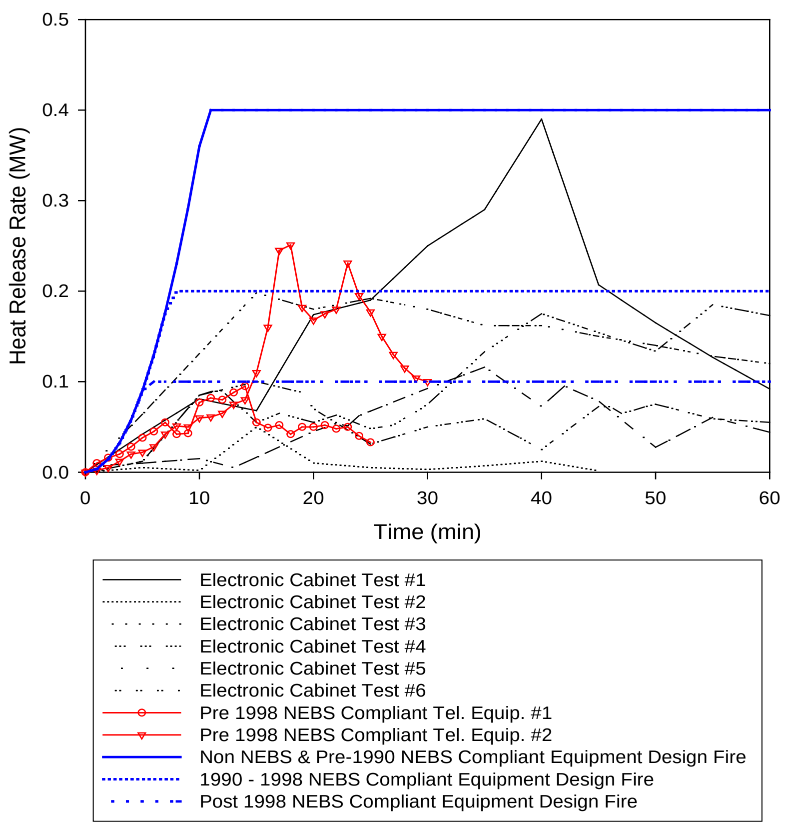
NEBS GR63 Compliant Telecommunications Equipment

- Most telecommunications equipment complies
- Approx 90% of fires fall between 15 and 20 kW peak
  - Heat Flux <15 kW/m^2
  - No spread beyond rack
- Design fires grow as t^2 (α=0.001) to a steady state of 100 kW

Design Fire Scenarios

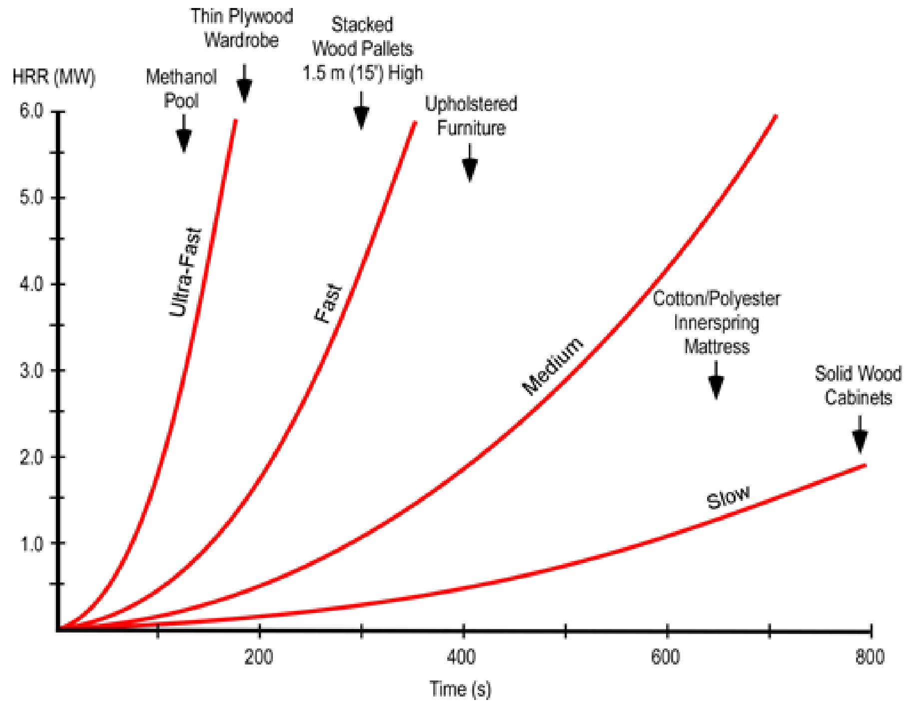
UL 60950 Listed IT Equipment

- Small-scale fire resistance tests limit ignitibility
- Limited energy components
- Tests conducted by VTT for nuclear power applications characterize equipment
  - 0.5-1.5 kW line burner source
  - Slow growth to peak <400 kW
- Design fires grow as t^2 (α=0.001) to a steady state of 200 kW



Proposed Design Fires

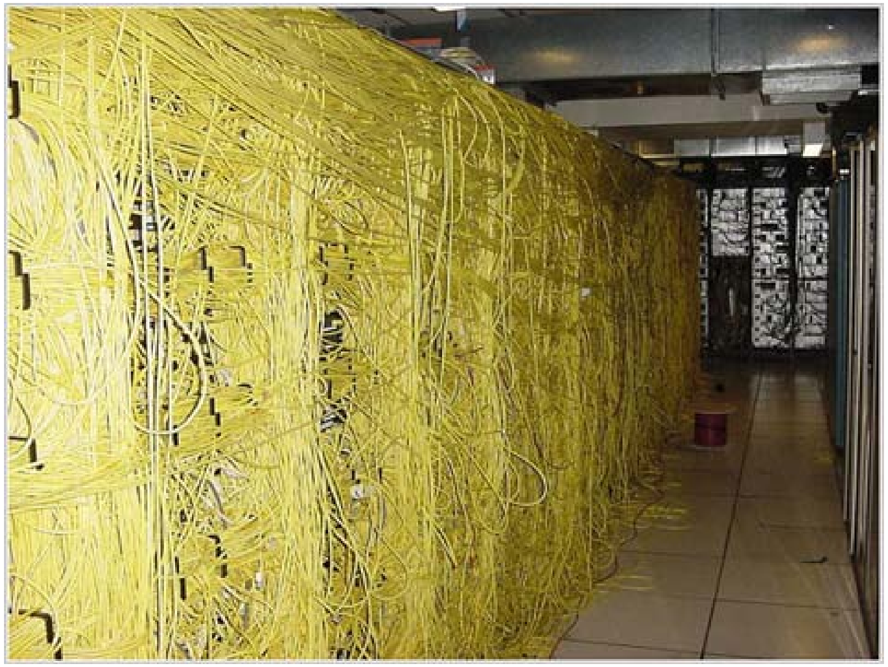
- Design fires grow as t^2 (α=0.001) to a steady state of
  - 200 kW
  - 100kW
  - 25kW
  - Smoldering?



T-squared fires with parametrically varying growth times are commonly used as design fires across a broad range of applications

Conclusions

- Existing *cfd* models should be capable of predicting smoke detector response in the high airflow environment of data centers
- Same models should be able to predict local concentrations of gaseous agents within equipment and at cable trays
- Reasonable design fires can be identified from existing fire test data
- Experiments will be needed to validate and to establish uncertainties
- Some data centers may lie outside the normal distribution



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