Energy Savings by Cool Roof

A case study of two buildings in Hyderabad

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IIIT-HYD

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Acknowledgements

- Sponsor
  - USAID
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  - Satyam
  - IIIT Hyderabad

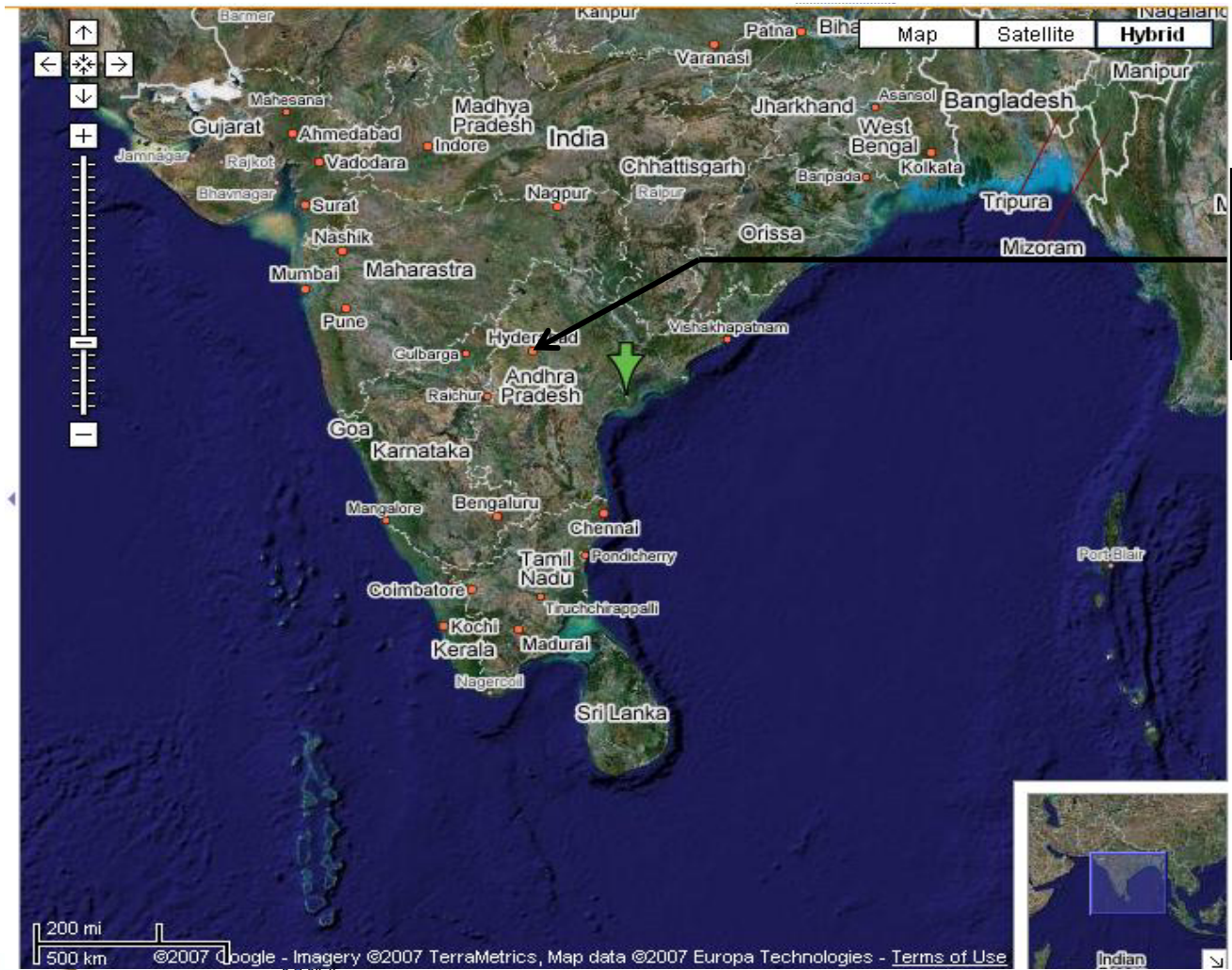
What is a cool roof?

- A surface with high solar reflectance and high thermal emittance
  - White surfaces are the coolest
  - There are also cool-coloured surfaces
  - Bare metal surfaces (with low thermal emittance) become hot in sunlight

Background

- Goal
  - To demonstrate energy and peak demand savings
- Building choice
  - Two identical buildings with separate AC for top floor
- Demonstration activities
  - Monitor energy savings, heat flux, surface temperatures in parallel and series experiments for:
    - concrete – white
    - concrete – black
    - black – white

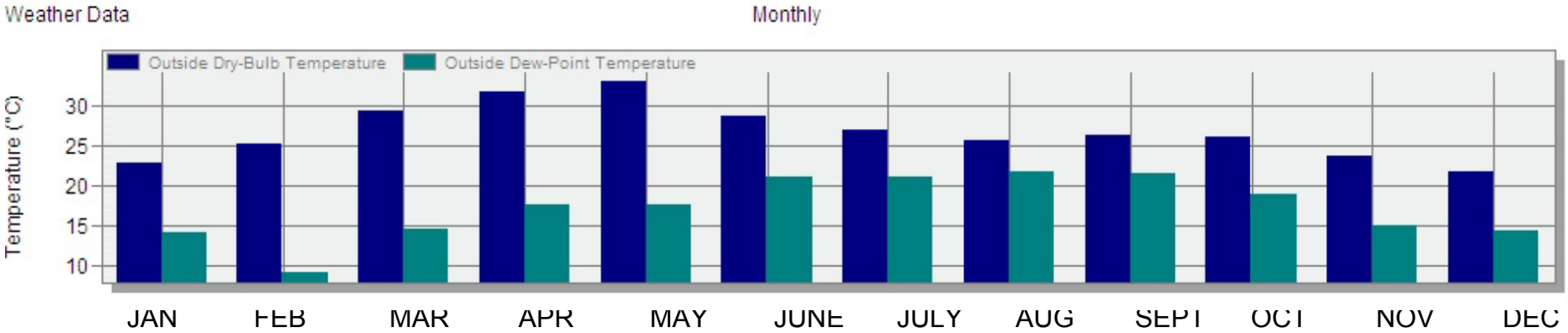
Location – Hyderabad India



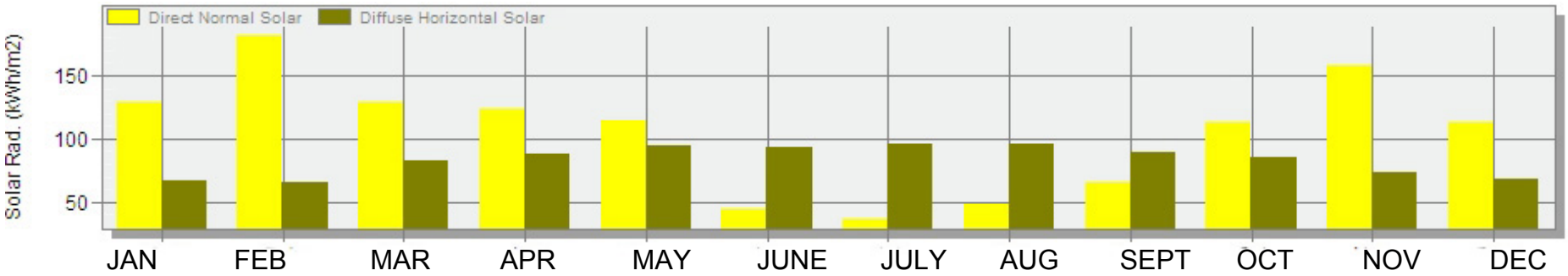
Hyderabad, A.P, India.

Satellite view

Hyderabad climate



Temperature



Solar Radiation

The Buildings

Satyam Learning Center (Hyderabad)

Two almost identical buildings – West Bldg and East Bldg

West building – front elevation

Lab interiors on the top floor

The experiment

- Objective – To measure the effect of the cool roof on AC energy on two identical buildings

- Three phases of the experiment
  - Phase 1: Both roofs concrete
  - Phase 2: West building – White, East – Black
  - Phase 3: West building – White, East – White

Preparatory phase

Date	Activity
July to Aug 2005	Identification of suitable buildings
Sep to Oct 2005	Developing monitoring protocol
Nov to Dec 2005	Procuring and calibrating the equipment
Jan 2006	Shipping

Monitoring periods and roof conditions

Phase	Period	Roof - West Building	Roof - East Building
Prep.	13-15 January, 2006	Monitoring equipment installed	Monitoring equipment installed
Phase I	**16 January to 22 March, 2006**	**Concrete roof**	**Concrete roof**
Trans.	23-26 March, 2006	White coating of roof	Black coating of roof
Phase II	**27 March to 22 July, 2006**	**Cool roof**	**Hot roof**
Trans.	23 July to 3 August, 2006	As-Is roof	White coating of roof
Phase III	**4 August to 16 December, 2006**	**Cool roof**	**Cool roof**

Applying the cool roof

First coat of cool roof

Normal gray surface

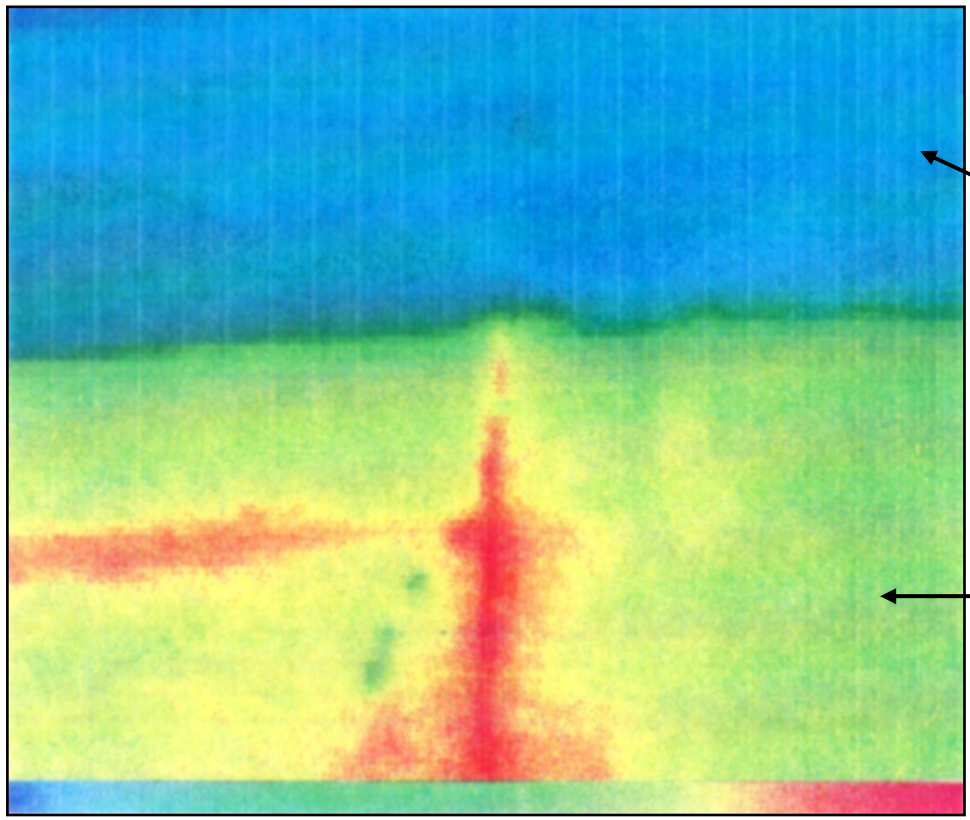
Applying the hot and cool roof

Existing gray roof

One coat of black roof on East bldg.

Three coats of cool roof on West bldg.

Roof-coating edge Infra-Red image



Fresh white coating

Dark seams

uncoated

100°F **180°F**

Temperature

Source: Dr. Hashem Akbari, LBNL, USA

Measuring the reflectivity of roofs (ASTM E1918)

Building characteristic data

- Floor area
- Number of stories
- Roofing material, age, and reflectance
- Roof insulation
- Plenum ventilation
- Cooling
- Air-handling systems
- Building schedules
- Lighting and systems schedules
- Thermostat settings

Monitoring points

- ***Weather:*** Wind speed, outdoor temperature and relative humidity, solar flux
- ***Energy:*** Whole-building electricity use, cooling-electricity use, heat flux through roof
- ***Temperature:*** Roof surface, roof underside, plenum air, inside air, return air

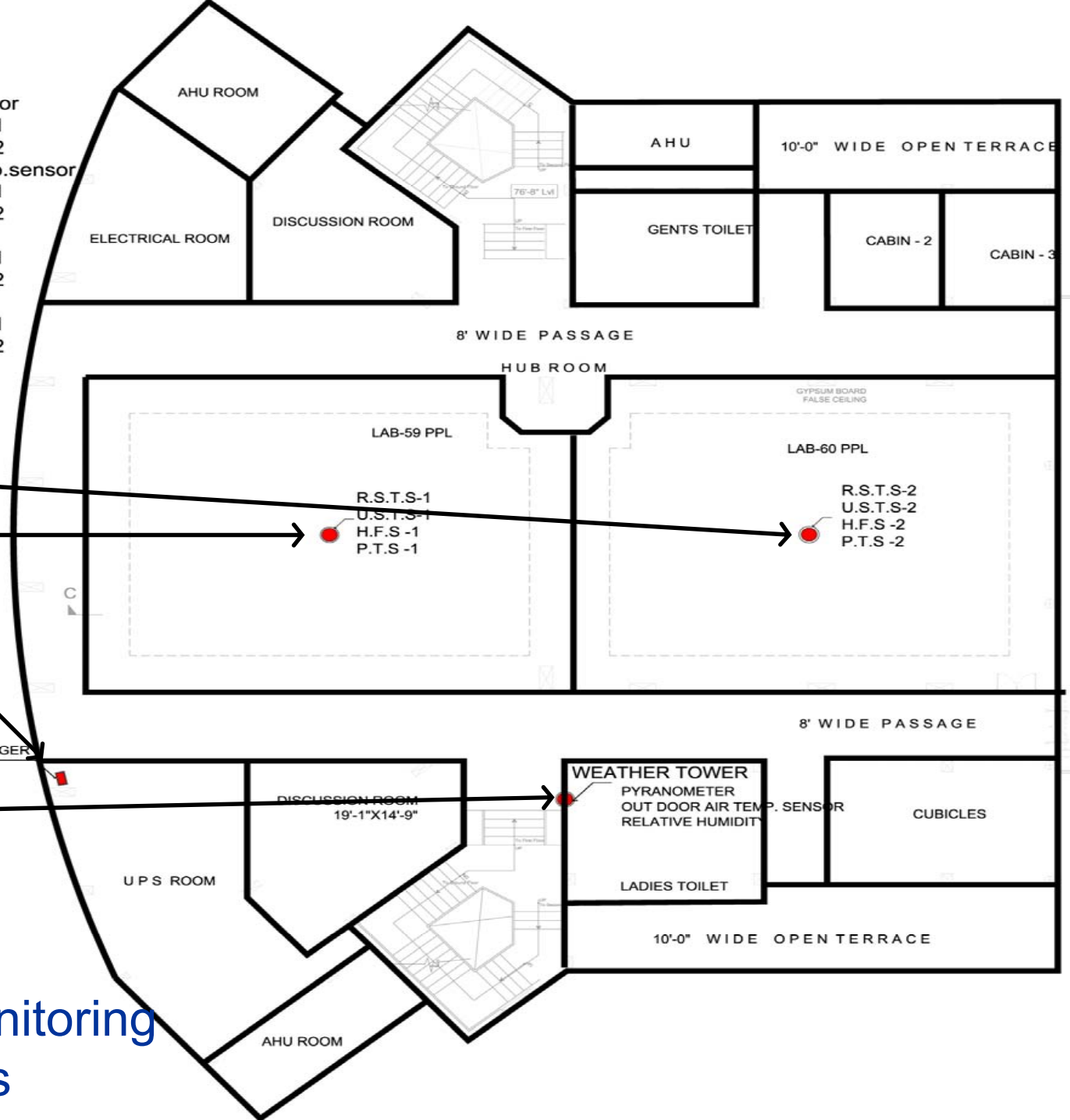
NOTE:

R.S.T.S - Roof Surface Temp. Sensor
- R.S.T.S-1 - Location 1
- R.S.T.S-2 - Location 2

U.S.T.S - Under Roof Surface Temp.sensor
- U.S.T.S-1 - Location 1
- U.S.T.S-2 - Location 2

H.F.S -Heat Flux Sensor
- H.F.S -1 - Location 1
- H.F.S -2 - Location 2

P.T.S - Plannum Temp. Sensor
- P.T.S -1 - Location 1
- P.T.S -2 - Location 2



Sensors

Datalogger

Weather tower

SLC West -monitoring locations

Sensor specifications

Measurement Points	Sensor Type	Locations
8 indoor air temperatures	Campbell Scientific 108-L temperature probe	1 in each of 4 ceiling return plenums and 4 conditioned spaces (west building Labs 1 and 2; east building Labs 1 and 3)
1 outdoor air temperature	Campbell Scientific 108-L temperature probe inside fan-aspirated radiation shield	1 on weather tower near center south side of west building roof
1 outdoor air relative humidity	Vaisala HMP45C-L relative humidity and air temperature probe inside naturally-aspirated radiation shield	1 on weather tower near center south side of west building roof
8 roof surface temperatures	Minco S667 surface temperature sensor with Minco TT246 temperature transmitter	1 on top surface of roof and 1 between bottom surface of roof and insulation above each of 4 ceiling plenums (west building Labs 1 and 2; east building Labs 1 and 3)
4 heat fluxes	Campbell Scientific HFT3 heat flux sensor	1 between bottom surface of roof and insulation above each of 4 ceiling plenums (west building Labs 1 and 2; east building Labs 1 and 3)
1 total horizontal solar radiation	Kipp and Zonen CM3 pyranometer	1 on weather tower near center south side of west building roof
14 HVAC, UPS, and lighting electric power consumptions	Continental Control Systems Wattnode WNA-3Y-400P pulse output watt-hour transducer with split-core current transformers	1 for each of 8 HVAC systems, 1 for each of 4 UPS systems, and 1 for each of 2 lighting systems serving conditioned spaces (west building Labs 1 and 2; east building Labs 1 through 4)

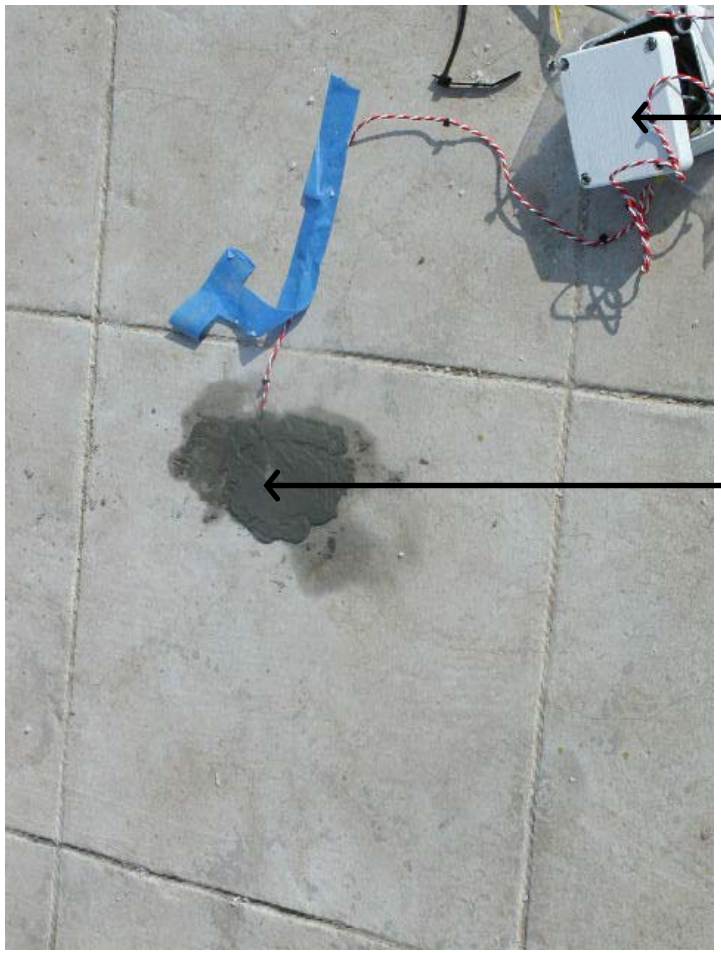
Weather tower

Minco TT246 Temperature transmitter

Vaisala HMP45C-L relative humidity and air temperature probe inside naturally-aspirated radiation shield

Campbell Scientific 108-L temperature probe inside fan-aspirated radiation shield

Surface temperature sensor



Minco TT246
Temperature transmitter

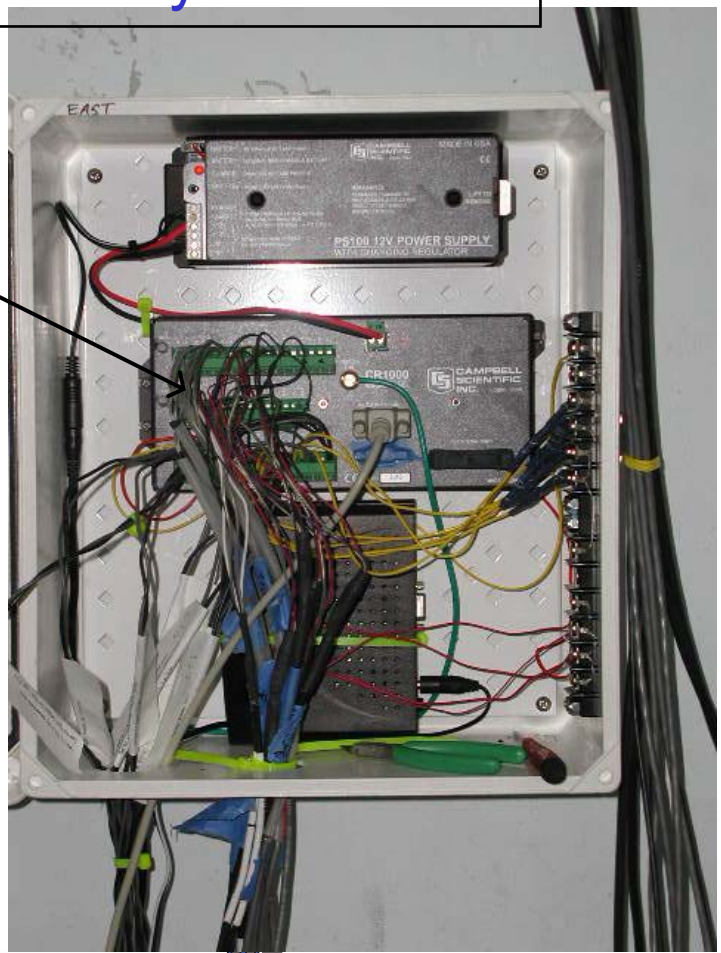
Minco S667 roof surface
Temperature sensor

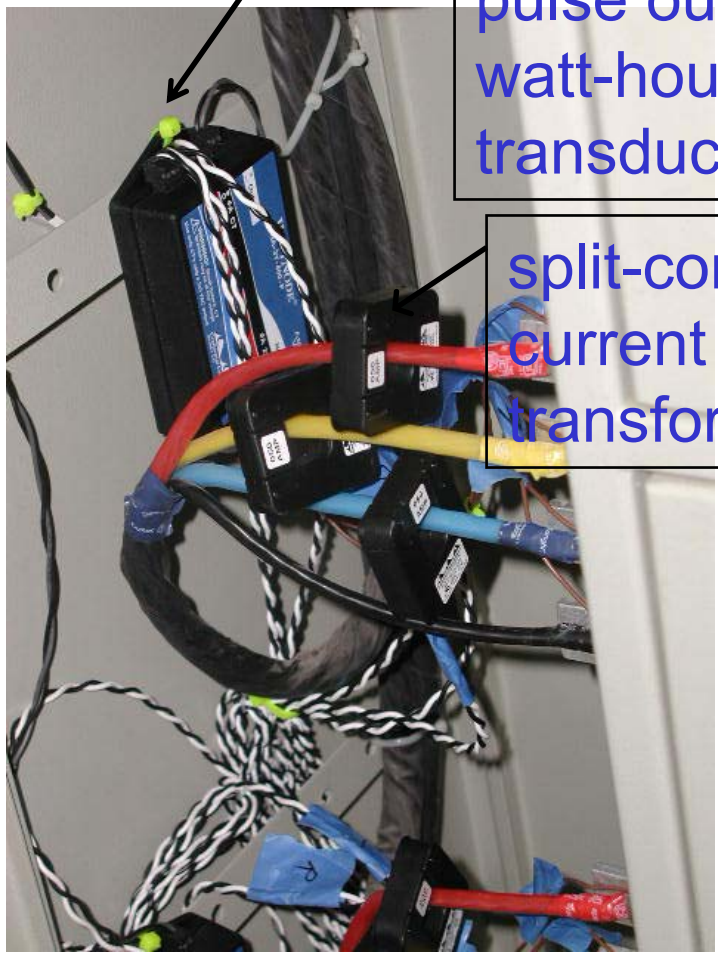
Data-logger and current transducers

Datalogger,Modem and Battery

Wattnode WNA-3Y-400P pulse output watt-hour transducer

split-core current transformers



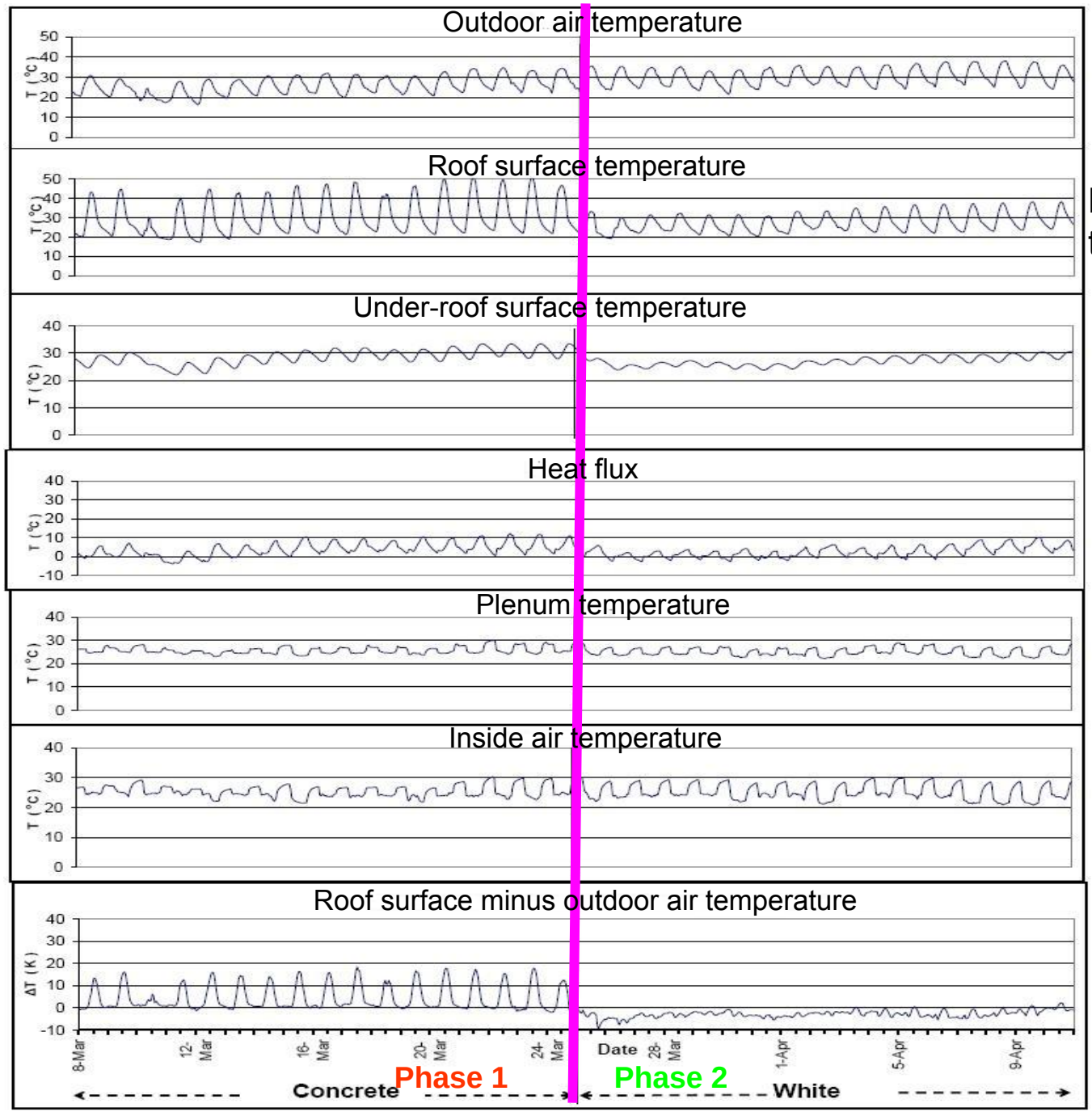


Date logged and frequency

- A Campbell Scientific XP-CR1000 13-bit data logger with a rechargeable battery backup power supply was used in each of the two buildings to collect data from the various sensors.
- Each sensor was scanned approximately every 1 second and average values were recorded every 30 seconds.
- Data were downloaded remotely about once a week using Campbell Scientific PC 400 software and a modem connected to the RS232 port of the data logger.
- Out-of-range data were investigated to determine whether a sensor or monitoring error existed, and appropriate corrective actions were taken if needed.

Observations

Measurements for the Phase 1 & 2 – West bldg



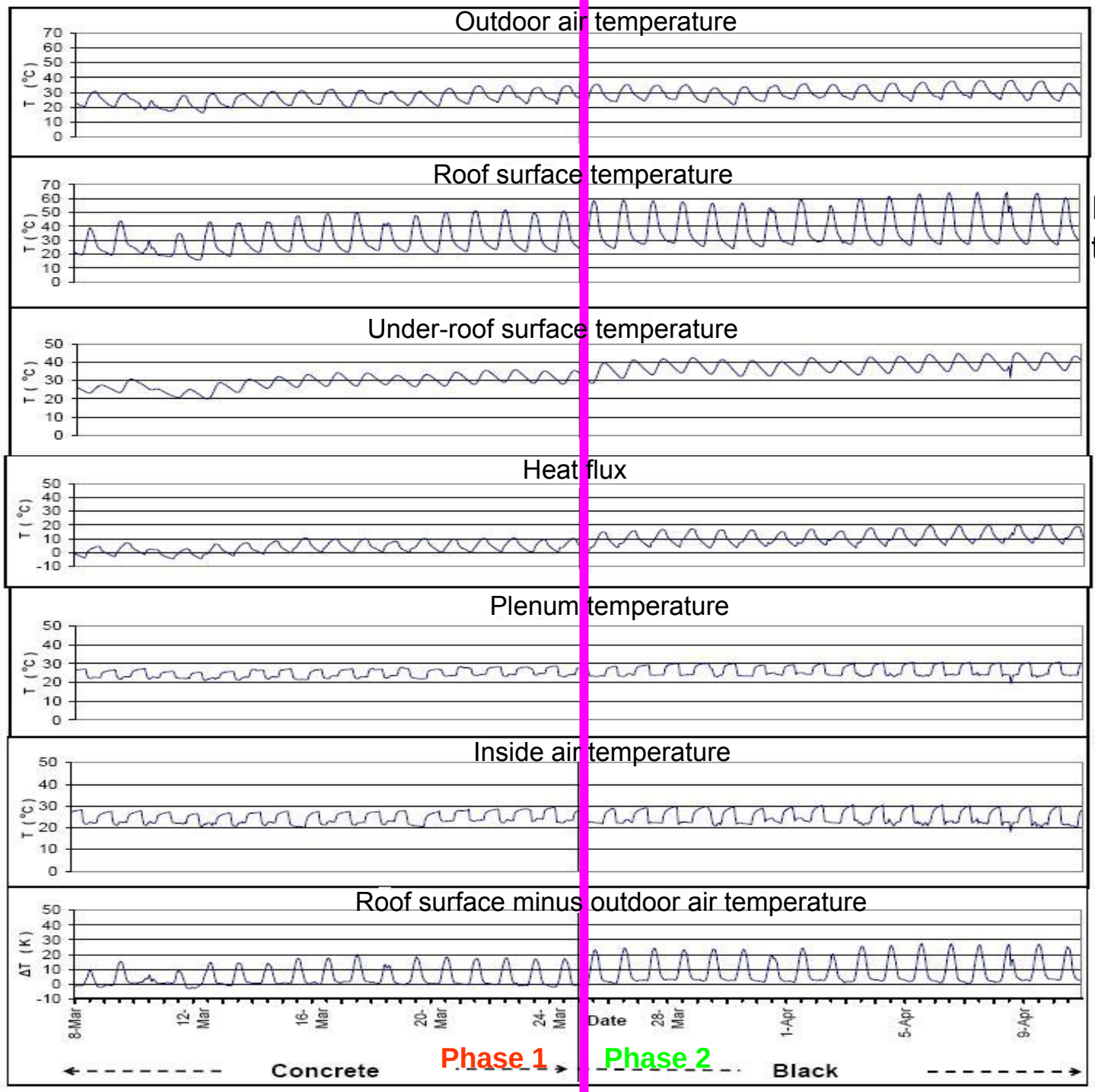
Drop in surface temp by 20°C

Drop in Underside temp by 5°C

Drop in H.F by 8 W/m^2

Drop in Plenum temp by 4°C

Roof surface temp is equal to or less than ambient temp



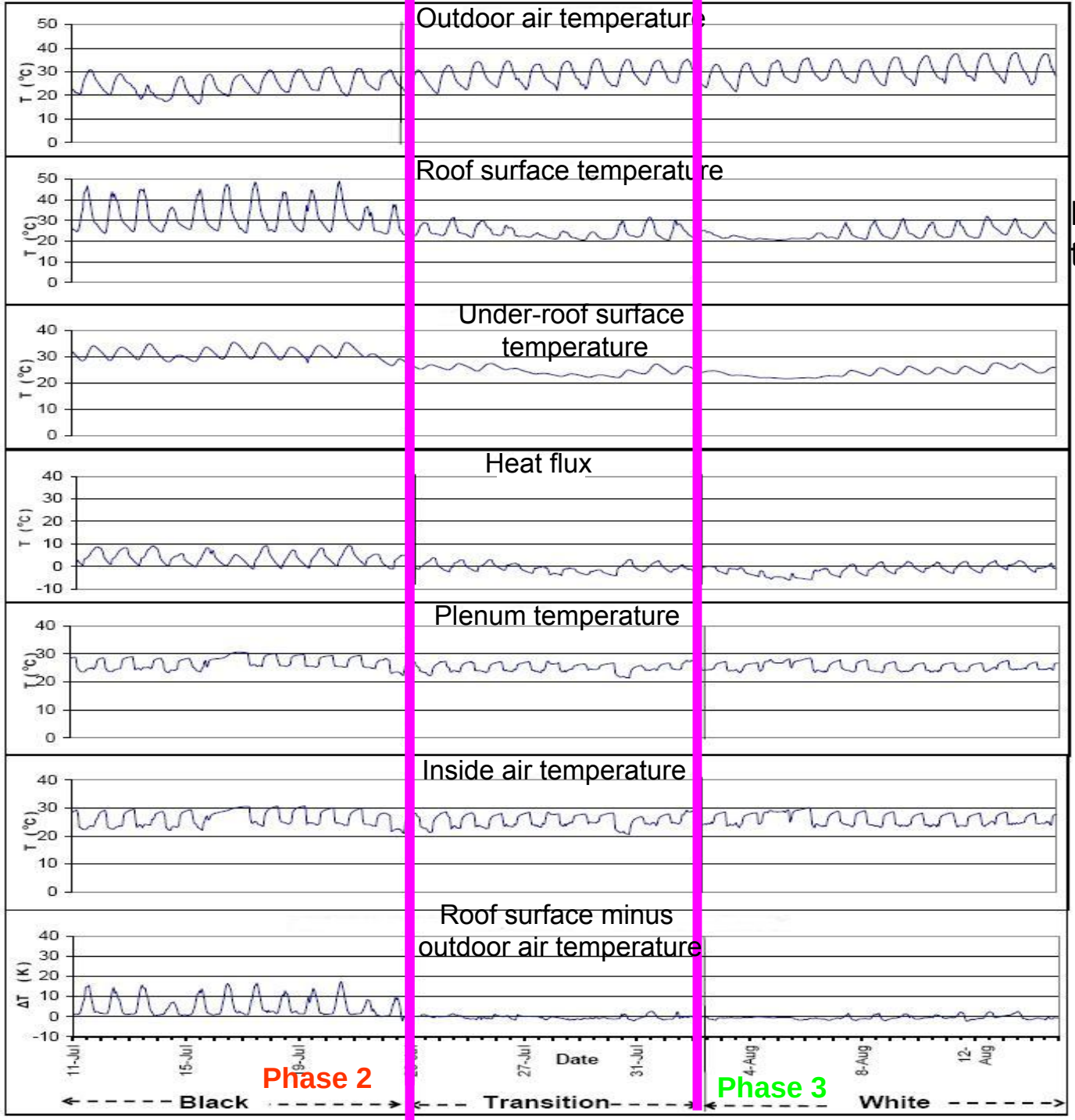
Increase in surface temp by 20°C

Increase in Underside temp by 10°C

Increase in H.F by 10 W/m^2

Increase in Plenum temp by 4°C

Roof surface temp is more than ambient temp



Drop in surface temp by 20°C

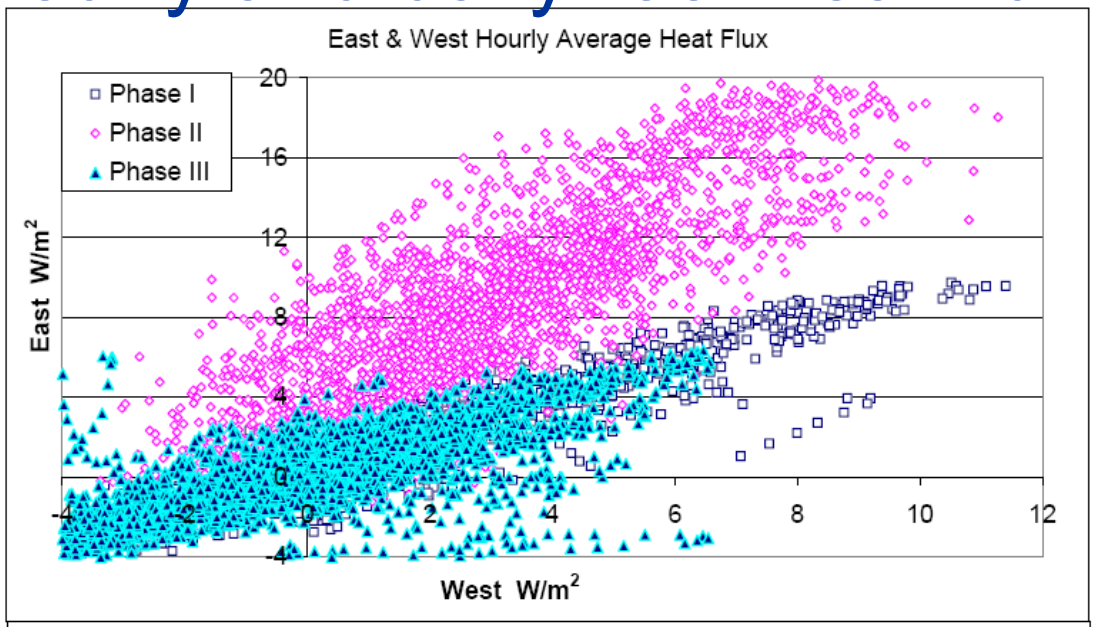
Drop in Underside temp by 5°C

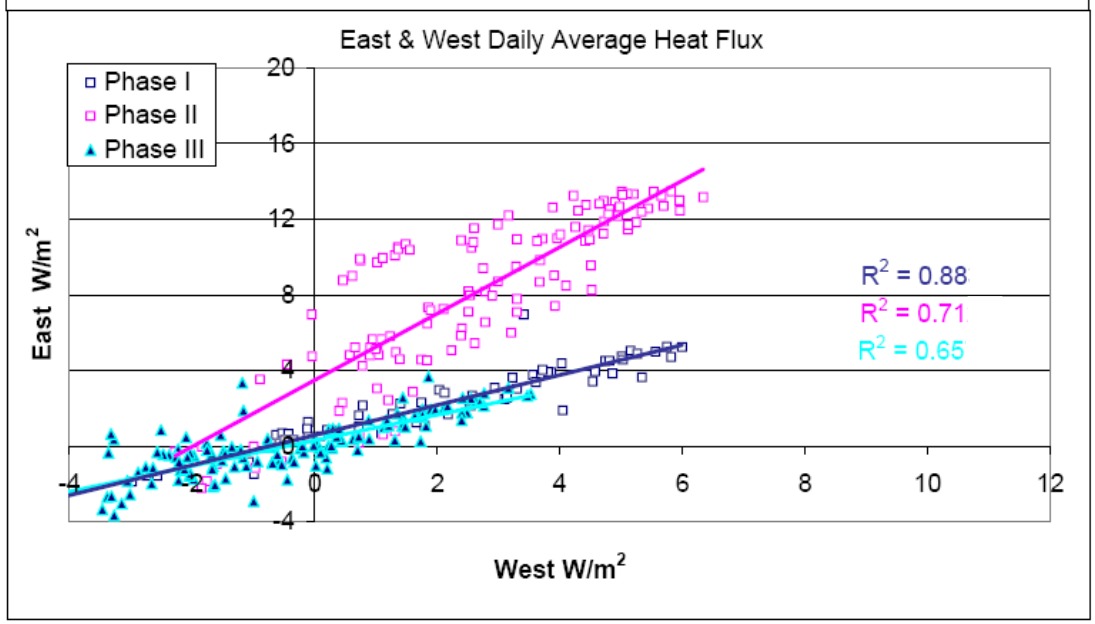
Drop in H.F by 8 W/m^2

Drop in Plenum temp by 4°C

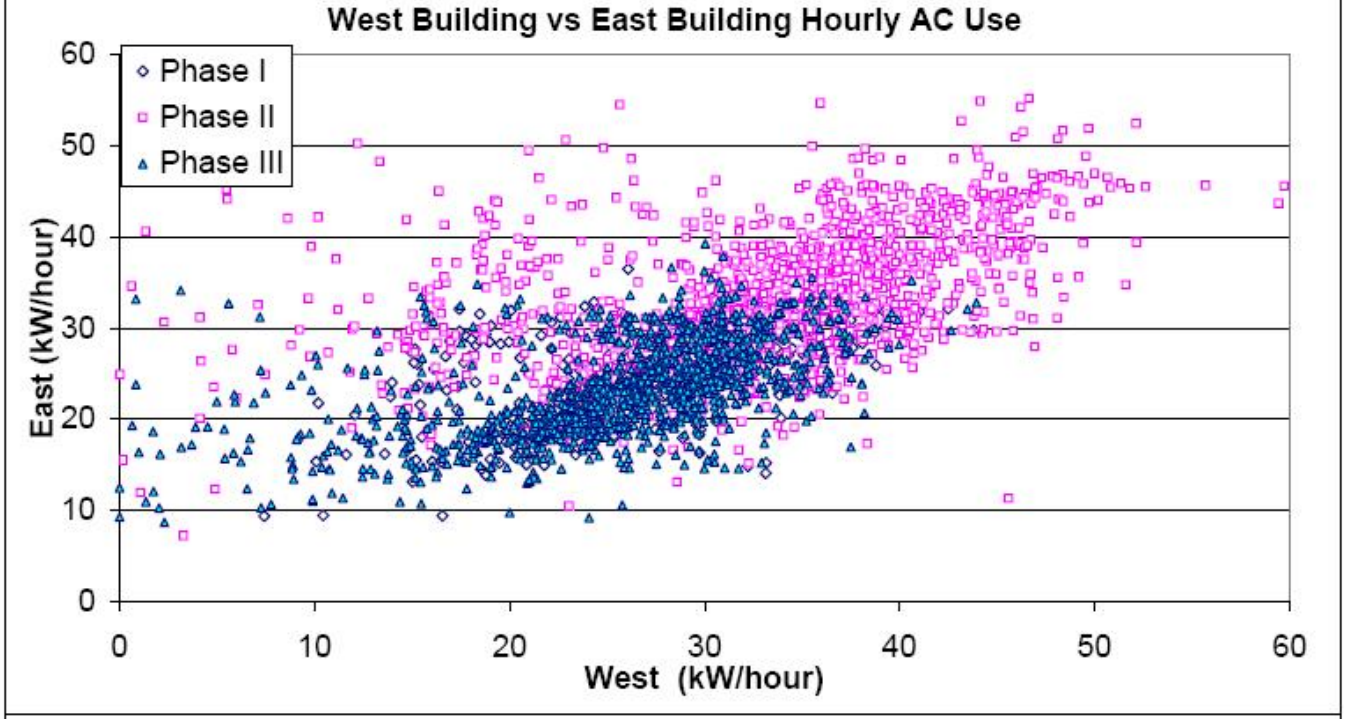
Roof surface temp is equal to or less than ambient temp

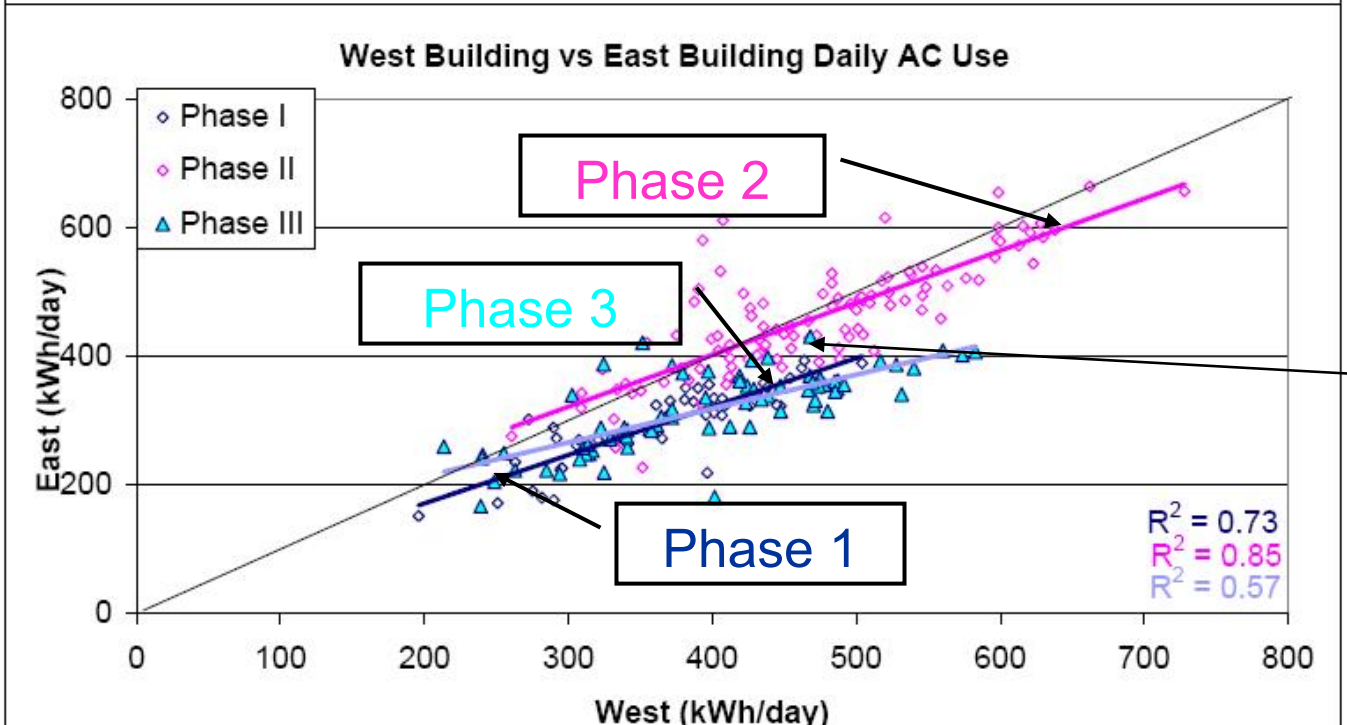
Comparison of East and West bldg hourly and daily roof heat flux





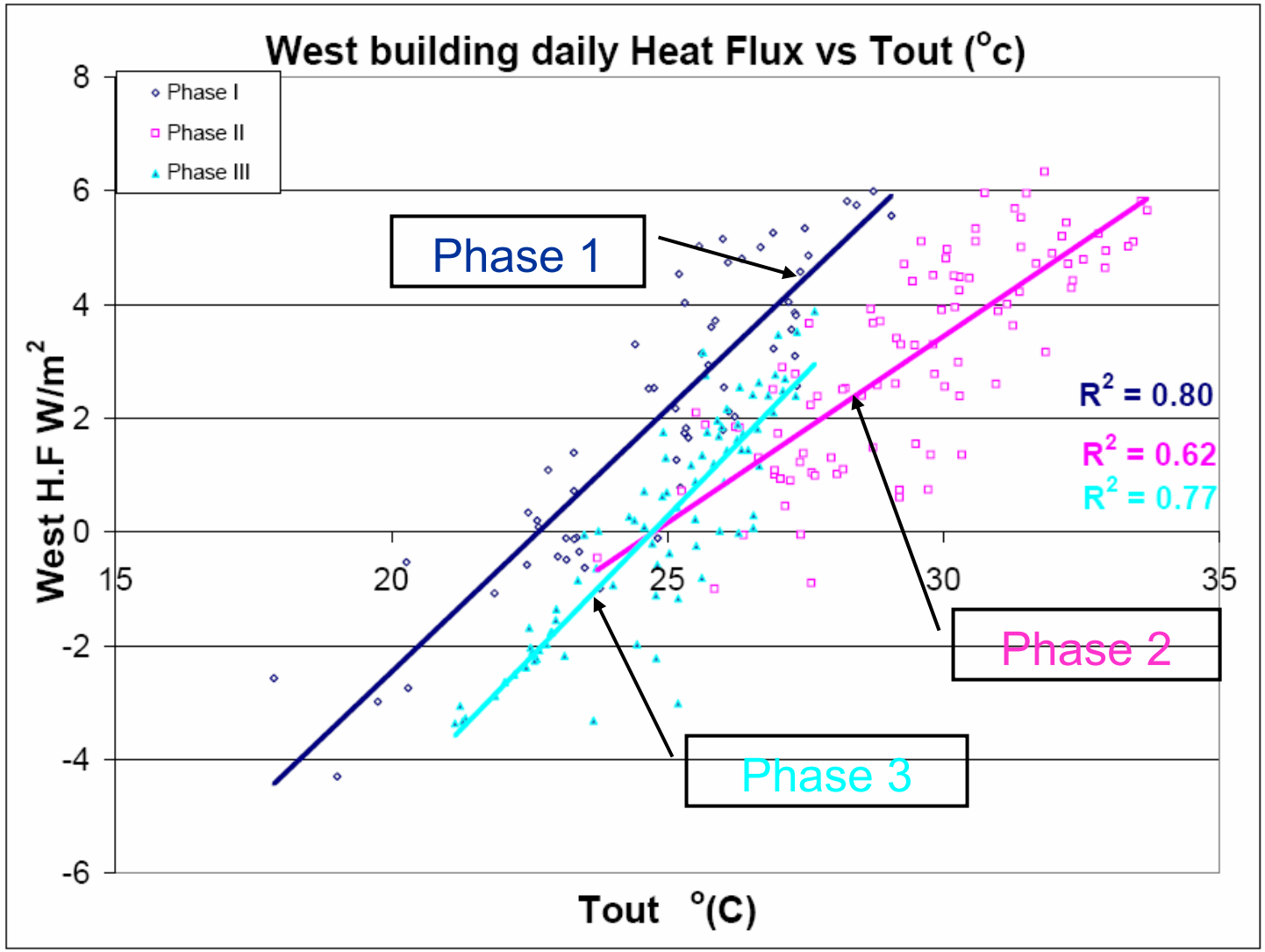
AC Use: Phase 1, 2 and 3 West vs East



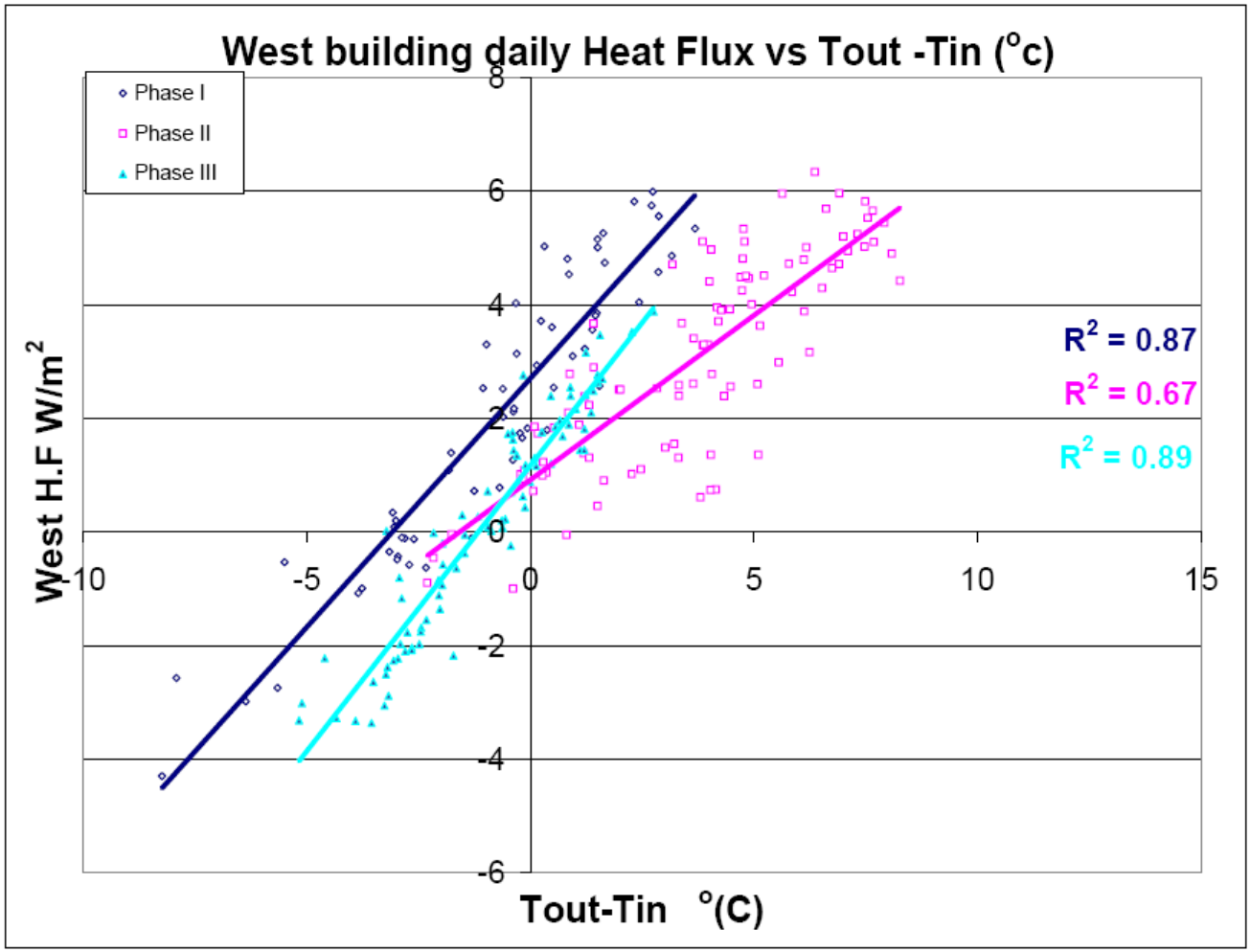


Drop in A.C consumption by 45-80 kWh/day (between white and black roofs)

Comparison of East and West daily roof heat flux vs outside air temperature



Comparison of East and West daily roof heat flux vs outside air minus indoor air temperature



Estimate of annual electricity savings

- Measured daily electricity savings
  - Black to white= 45 to 80 kWh
  - Gray to white = 30 to 53 kWh
- Building operates 25 days/month, 12 months = 300 days
- Estimated annual electricity savings = 9,000 kWh
- Roof area ≈ 700 m^2
- Annual savings per square meter = 13 kWh/m^2
- Monetary savings at Rs. 7/kWh = Rs. 90 $/m^2$/year
- Peak demand reduction = 5 W/m^2 (Rs. 20 $/m^2$/year)

Cost savings

- First cost saving:
  - Downsizing air conditioning: Rs. 190 /m^2 (cost of 1 ton = Rs. 35k, 1kW=1ton)
  - Transformer, deposit to electricity board = Rs. 11 /m^2
  - Longer roof life? (not considered here)
- Recurring cost
  - Electricity and peak demand = Rs 110 /m^2/year
- Total savings in 10 years: Rs. 1300/m^2

Hyderabad metropolitan-wide savings

- Assuming 1 million sft roof area per year new construction for next 5 years
- Reduction in demand = 2.5 MW
- At 5 crores per MW, savings = 12.5 crore
- Annual energy savings = 1.3 GWh (1 crore)
- In India assuming 10 million sft per year (conservative?)
  - Demand savings: Rs. 125 crores
  - Annual energy savings = Rs. 10 crores

Roofing materials and cool choices

Common roofing materials	Cool options	Pay back
Cement roof	White cement	< 1 year
Tiles	White/light colour tiles	Negative to 1
Buildup roof	White/light colour coating	3-4 years
Metal roof	White paint/coating	< 1
Mud house	White wash roof	More comfort

Simulations to estimate savings for different roof types and in different cities in India

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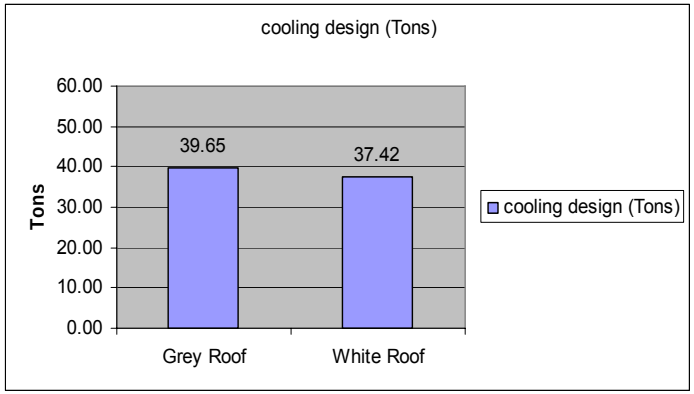
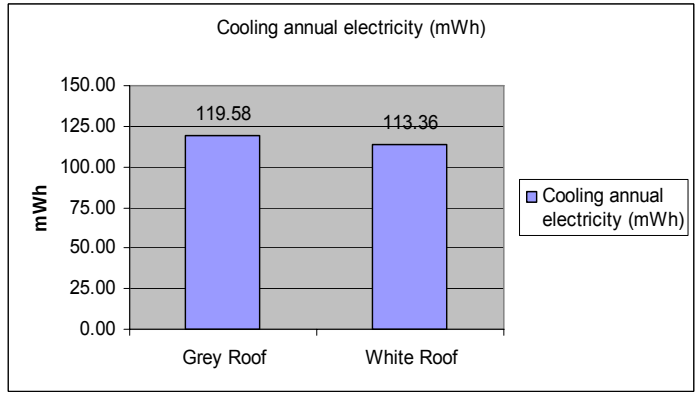
AC savings simulations

- Models used
  - Design Builder and EnergyPlus
- Prototype characteristics
  - 10,000 ft^2, square shape
  - Single storey
  - 30% glazing – double pane, Aluminium frame
  - IT office schedules and activities
  - Internal load of 4 w/ft^2

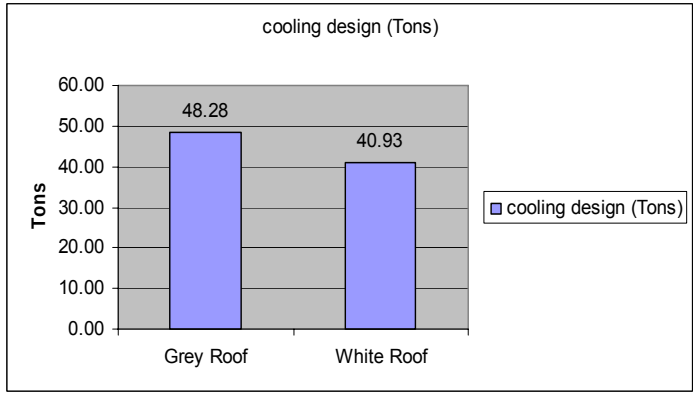
Simulated annual AC consumption in Hyderabad for different roof types

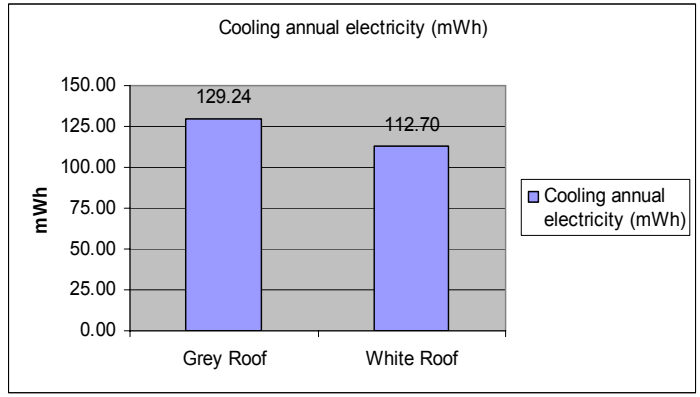
Roof with insulation and air gap



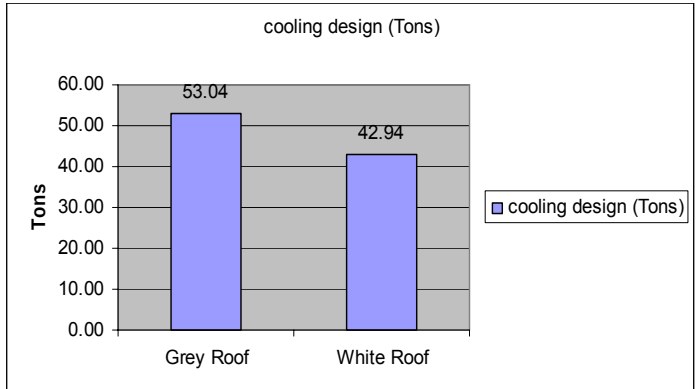


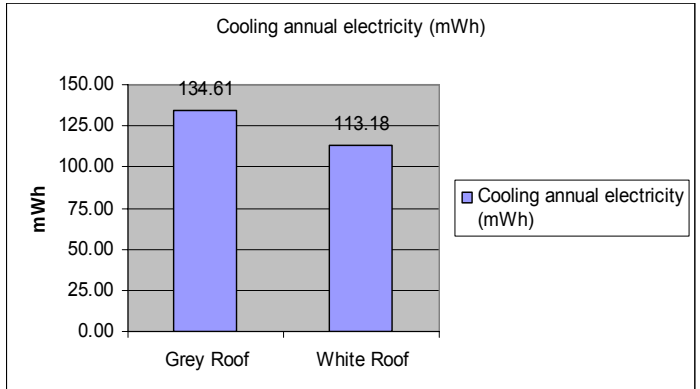
Roof with air gap



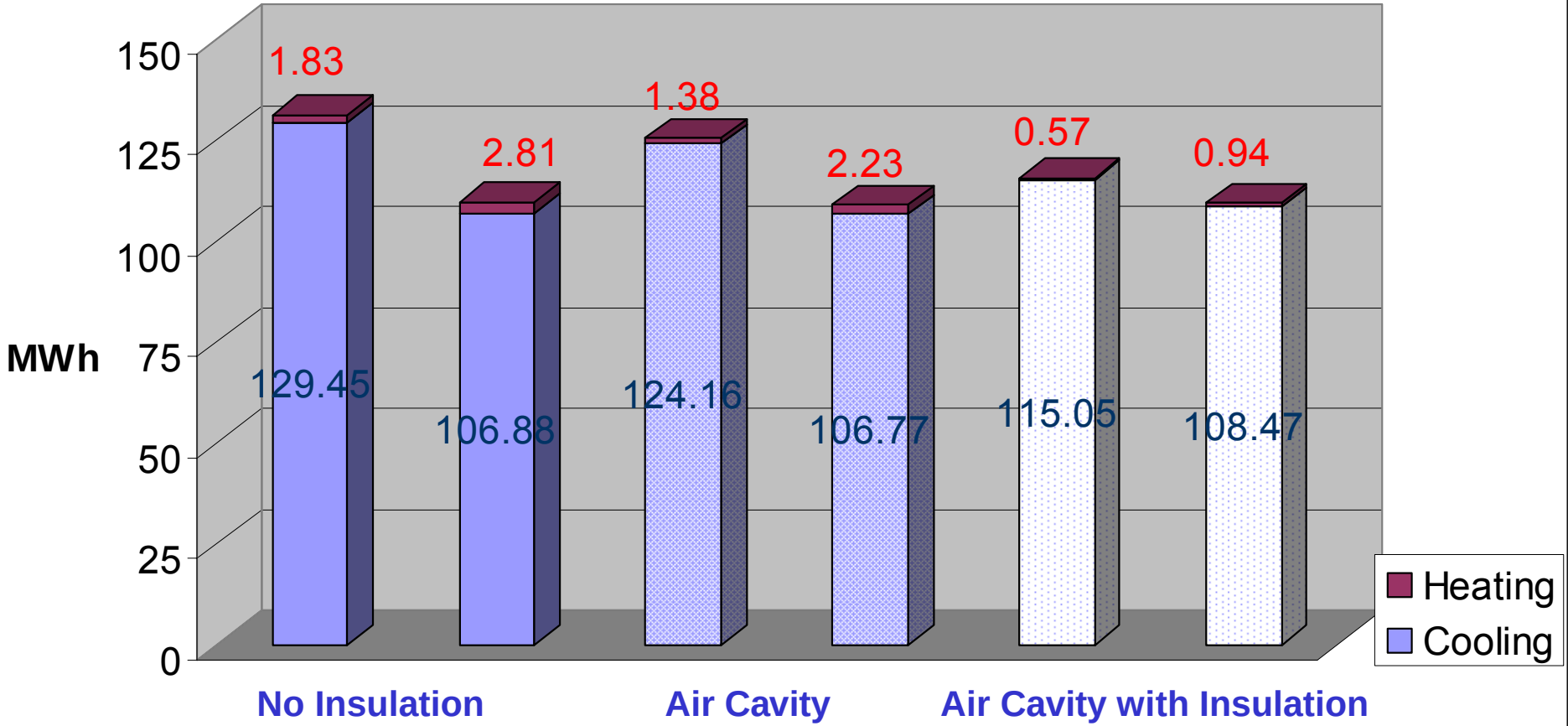


Roof with no air gap and insulation





Simulated annual energy consumption in Delhi for different roof types



Savings in annual cooling and heating (kWh/m^2 & %)

City	No Insulation	Air Cavity	Air Cavity with Insulation
Hyderabad	21.42 15.92%	16.54 12.80%	6.22 5.20%
Delhi	21.59 16.45%	16.54 13.18%	6.21 5.37%

References:

- http://cbs.iiit.ac.in/coolroof.html
- http://heatisland.lbl.gov
- http://coolcolors.lbl.gov

Thank You