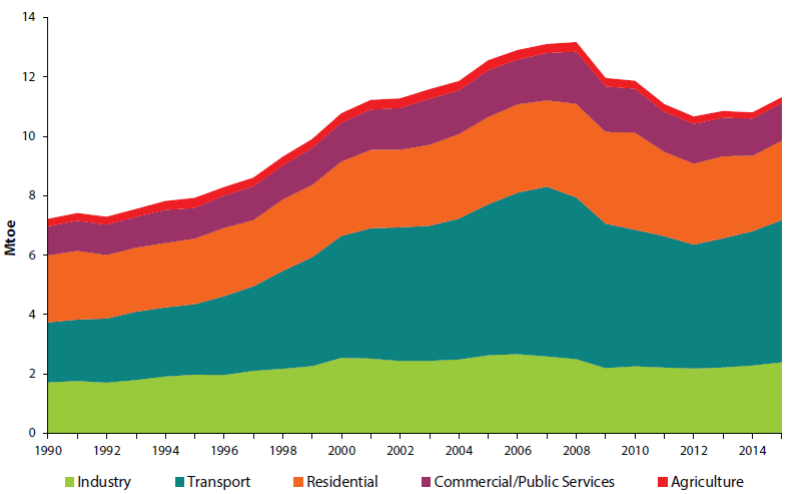
Presentation Outline

- Objective
- Background
- IAQ
- Study
- Results

Objective

- Energy retrofit of domestic dwellings
  - IAQ
  - Thermal comfort

Residential sector – Energy



http://www.seai.ie/Publications/Statistics_Publications/Energy_in_Ireland/Energy-in-Ireland-1990-2015.pdf

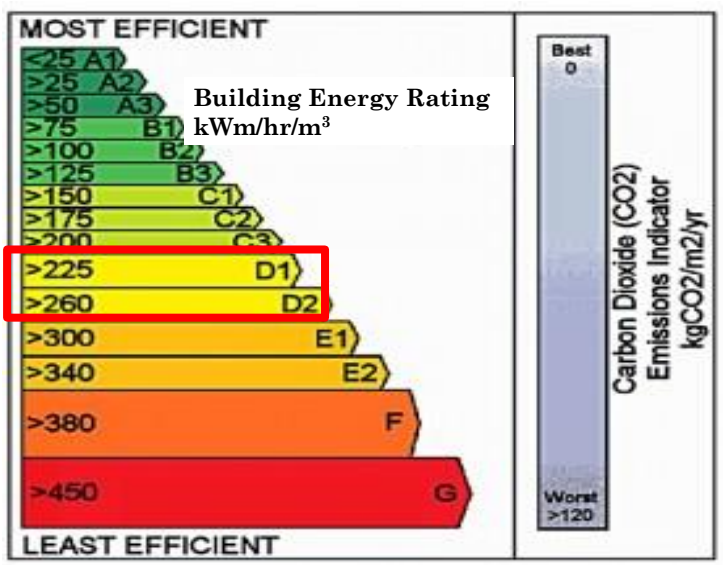
Residential sector – Energy related CO_2 emissions

- 1990 – 2015
  - Building Regulations
  - Irish Government energy saving incentives
  - Behavioural changes
- CO_2 emissions - 25%

- National Energy Authority
  - *Better Energy Homes Scheme*
  - *Warmer Homes Scheme*
  - *Better Energy Communities*
- 2015
  - 300,000 homes
  - Target 75,000 homes /yr 2020

- National Energy Authority
  - *Better Energy Homes Scheme*
  - *Warmer Homes Scheme*
  - *Better Energy Communities*

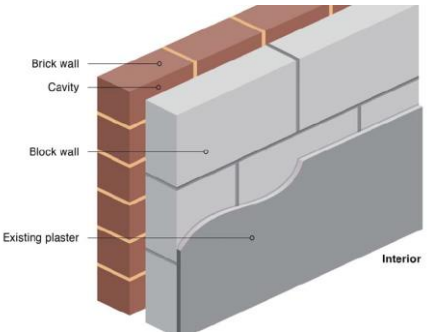
Energy performance certificate



Selection criteria – construction type

- Cavity wall

(110 mm cavity, 25 -60 mm)



- 15 homes,
- 2000
- 100 – 126 m^3
- 3 bedroomed semi – detached

https://www.nsai.ie/Our-Services-(1)/Agrement/SR-54-Launch/SR-54-workshop-JR.aspx

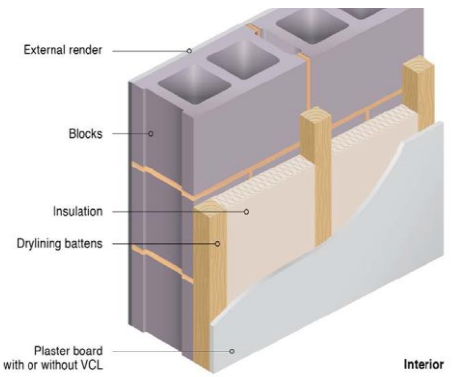
Selection criteria – construction type

- Cavity wall (CW)

(110 mm cavity, 50 mm)

- 7 CW & 8

Hollow block/CW



- Hollow block
  - Concrete block – two hollow cores
  - 15 – 25 mm insulation studs -plasterboard lining

https://www.nsai.ie/Our-Services-(1)/Agrement/SR-54-Launch/SR-54-workshop-JR.aspx

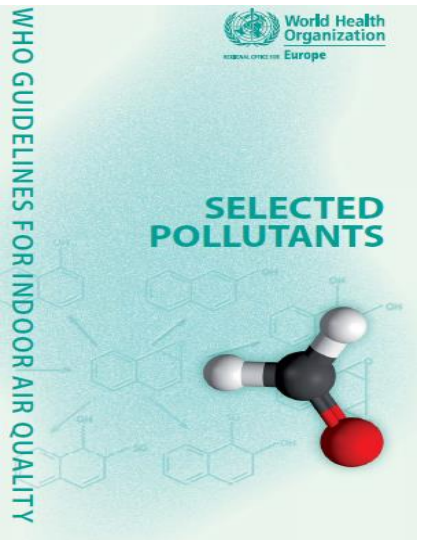
Pre Retrofit

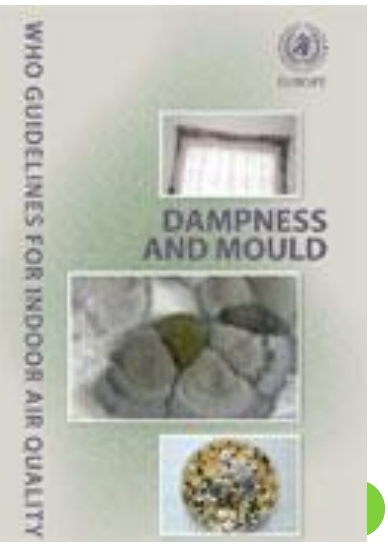
External wall / CW	Cavity wall – 50 mm polystyrene insulation board (110 mm cavity)
External wall/ HB/CW	plaster board internal lining w/ 15 – 25 mm insulation (cavity wall around front lower window)
Attic	100 mm thick mineral wool insulation
Windows and doors	Wood and PVC 12 mm double glazed units
Boiler	Balanced boiler (66% efficient),manual control - timer control for one zone
Ventilation (Kitchen & Bathroom)	Natural ventilation – extract fan in kitchen only Background wall vents (only HB)

Selection criteria (n=15)

Average occupancy rate in Ireland is 2.7

Selecting pollutants to measure





What did we measure ?

Pollutant	Indoor source
Particulate matter ($PM_{2.5}$)	Solid fuel combustion, outdoor air
NO_2	Gas/wood/oil/kerosene, traffic pollution
Mould and dampness	Excess humidity, ventilation
Radon	Natural source
TVOCs	Cleaning products, furnishings, varnishes, glues etc

What did we measure ?

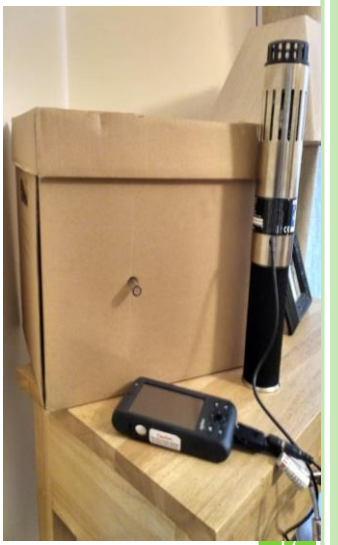
Pollutant	Source
BTEX	Smoking, building materials, attached garages
CO	fossil fuels, incense, faulty appliances
Formaldehyde	Cleaning products, furnishings, varnishes, glues etc
Dust mites	Pets, outdoors, poor ventilation

What else did we measure ?

- Building air tightness
- Room Air Exchange Rate
- Temperature
- Relative humidity

How did we measure ?

- 24 hour period
  - TSI SidePak AM510 Personal Aerosol Monitor logged real-time data on airborne $PM_{2.5}$
  - CO & CO_2 - GrayWolf IQ-610
  - TVOC - GrayWolf TG-502
  - Formaldehyde – GrayWolf RM-108
- 2-3 week period
  - NO_2 & BTEX levels - Gradko passive diffusion tubes



How did we measure ?

- 24 hour period
  - Temperature & relative humidity GrayWolf IQ-610
- Building air tightness ($m^3.h.m^2$)
  - Blower door test – ISEN13829:2000
- Room air exchange rate
  - CO_2 – tracer gas

How did we measure ?

- Grab sample
  - Dust mites

    SKC Carpet Tester suction sampling kit

- 3 months
  - Radon -passive alpha track radon detectors.

What other information did we collect ?

Researcher
- Building type
- Heating type
- Cooking fuel
- Occupant rate

Occupant
- Thermal comfort
- Occupant behaviour

THE OCCUPANTS – ACTIVITY DIARY

DAY ONE																
IN THE MAIN LIVING ROOM **Did any of the following happen?** **(Please tick all that apply)**	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm	5pm-6pm	6pm-7pm	7pm-8pm	8pm-9pm	9pm-10pm	10pm-11pm	11pm – 7am	COMMENTS
Windows opened																
Coal/Wood/Peat fire burning																
Candles/incense burning																
Gas hob used																
Electric cooker used																
Toaster/grill used																
Extractor fan on																
Cleaning/polishing																
Vacuum cleaner used																
Pets were present																
4 or more people were present																
Wall or window vents present open/closed																

The retrofit - Cavity wall homes

300 mm thick mineral wool insulation

Residual 110 mm cavity filled with extruded polystyrene beads

125 mm core wall vents
Or vents were cleaned out and serviced

Retrofit specification – Cavity wall

	Pre Retrofit	Post Retrofit
Windows and doors	Wood/PVC 12 mm double glazed units	PVC 24/28 mm double glazed units
Boiler	Balanced boiler (66% efficient)	Condensing boiler (90% efficient), zoned heating w/thermostat, pipe work insulated
Ventilation (Kitchen & Bathroom)	Extract fans in kitchen	Extract fan with humidity control

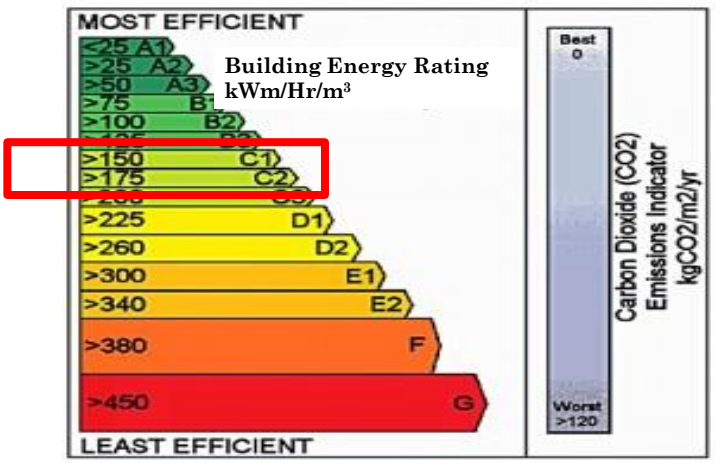
The retrofit - Hollow block/CW homes

300 mm thick mineral rock wool insulation

extruded polystyrene beads only around the front wall

vents were cleaned out and serviced

Building performance certificate



Indoor air pollutants – comparison guidelines

- PM2.5 – WHO 2006
- Formaldehyde, CO, NO2, benzene – WHO 2010
- TVOCs – UK building Regulations

Indoor Environmental Quality

	Pre retrofit Mean (n= 7)	**Post retrofit Mean (n= 7)**	**p**
Air tightness ($m^3.h.m^2$) @ 50 Pa - CW	9.3 ($m^3/(h.m^2)$)	5.5 ($m^3/(h.m^2)$)	
Air exchange rate – CW	0.81 ACH	0.55 ACH	**<0.001**
	Pre retrofit Mean (n= 8)	**Post retrofit Mean (n= 8)**	
Air tightness ($m^3.h.m^2$) @ 50 Pa – HB/CW	9.3 ($m^3/(h.m^2)$)	8.6 ($m^3/(h.m^2)$)	
Air exchange rate – HB/CW	0.83 ACH (m^3/h)	0.7 ACH (m^3/h)	**<0.001**

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Significance level $p < 0.05$

Indoor Environmental Quality

Cavity wall	**Pre retrofit Mean (n= 7)**	**Post retrofit Mean (n= 7)**	**p**
Temperature (°C)	17.8 (0.9) 17.5 (0.8)	18.6 (0.6) 18.6 (0.6)	
Relative Humidity (%RH)	51.4 (3.0) 51.1 (2.0)	54.2(0.9) 54.0 (0.9)	
Hollow Block/CW	Post retrofit Mean (n= 8)	Pre retrofit Mean (n= 8)	
Temperature (°C)	17.3 (1.2) 16.8 (0.6)	18.3 (0.8) 18.0 (0.5)	**< 0.005**
Relative Humidity (%RH)	50.7 (2.1) 51.0 (2.0)	52.3(0.8) 52.2 (1.0)	

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Significance level $p < 0.05$

Indoor Air pollutants

- Concentrations of CO, BTEX, NO_2, no significant difference following the retrofit
- All within recommended Health Limits

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Indoor Air pollutants – Cavity wall

	Pre retrofit Mean (n= 7) (SD)	Post retrofit Mean (n= 7) (SD)	p
Formaldehyde (ppb)	**15.4 (3.8)**	**24.3 (3.0)**	**0.001***
$PM_{2.5}$ (µg/m³)	**10.0 (2.0)**	**18.0 (2.6)**	**0.005***
CO_2 (ppm)	**578.6 (94.0)**	**719.4 (114.0)**	**0.014***
TVOC (ppb)	**362.0 (73.0)**	**477.0 (38.0)**	**0.009***

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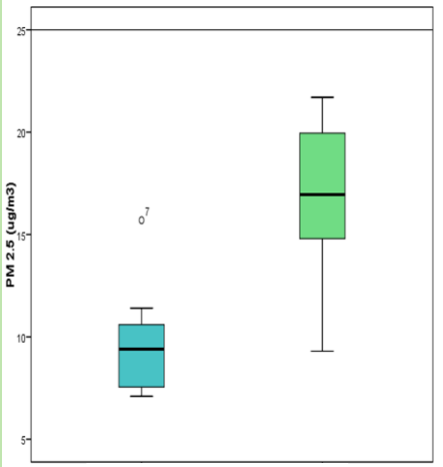
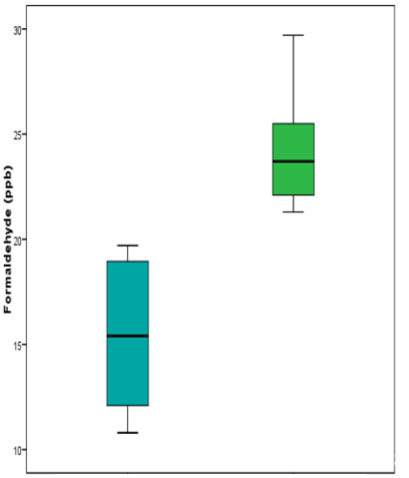
P value is significant at the 5% level of significance

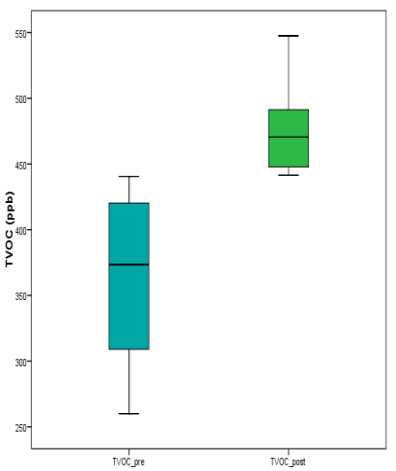
PM $_{2.5}$ 24 hr average concentration (µg/m^3) before and after the retrofit



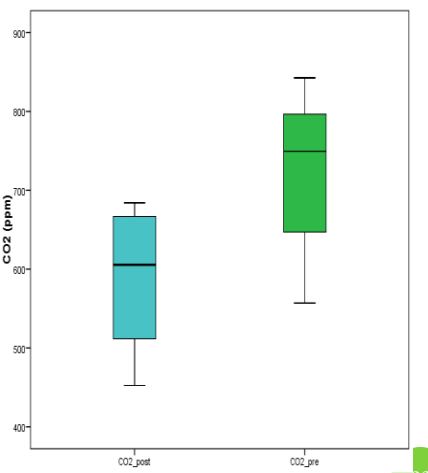
Formaldehyde 24 hr average concentration (ppb) before and after the retrofit



TVOC (ppb) 24 hr average concentration (µg/m^3) before and after the retrofit



CO2 (ppm) 24 hr average concentration (ppb) before and after the retrofit



Indoor Air pollutants – Hollow block/CW

	Pre retrofit Mean (n= 7) (SD)	Post retrofit Mean (n= 7) (SD)	p
$PM_{2.5}$ (µg/m^3)	**9.33 (2.6)**	**15.34 (4.0)**	**0.008***
CO_2 (ppm)	**566 (66.0)**	**671.0 (59.0)**	**0.003***
TVOC (ppb)	**375.6 (74.4)**	**462.0 (52.2)**	**0.032***

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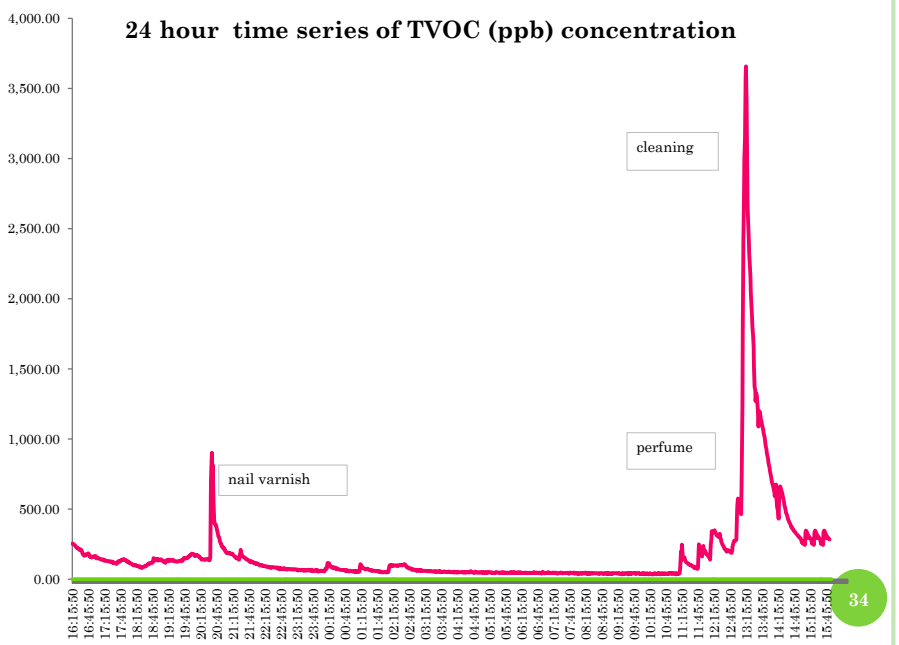
P value is significant at the 5% level of significance



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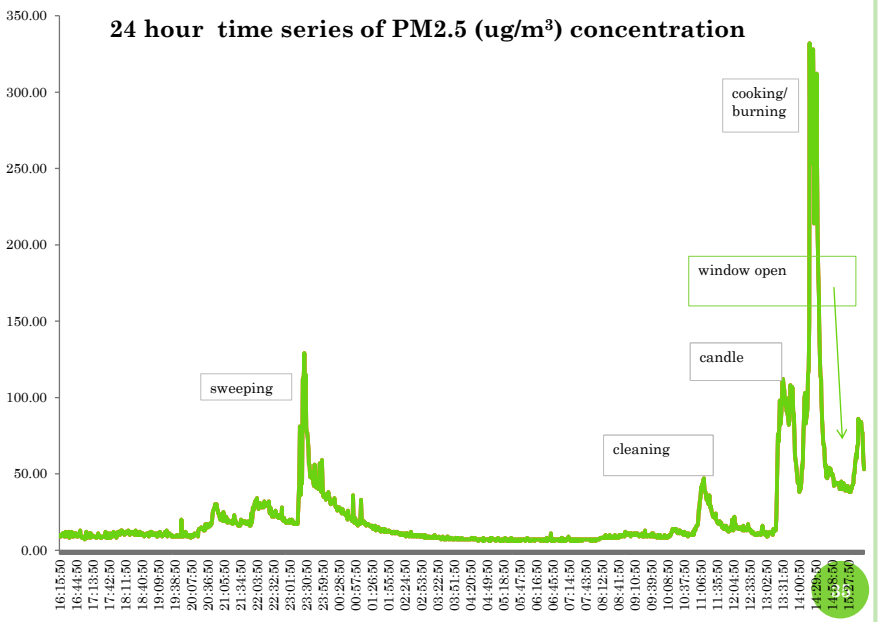

- Room Air Exchange rate correlated ;
  - $PM_{2.5}$ (µg/m^3) (R^2 = 0.4)
  - Formaldehyde (ppb) (R^2 = 0.4)

CONCLUSION

- Increase in airtightness and reduced ACH
- Improved occupant comfort
- levels of all IAP increased post retrofit
  - PM2.5, Formaldehyde, TVOC's
- What are IAP concentrations 12 months post retrofit?
- Education

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epa Environmental Protection Agency

NDP NATIONAL DEVELOPMENT PLAN

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Co-operative housing Ireland

NUI Galway OÉ Gaillimh

C-CAPS Ionad Aeráide agus Truaillíú Aeir Centre for Climate & Air Pollution Studies

REFERENCE MATERIAL

- http://www.seai.ie/Publications/Statistics_Publications/Energy_in_Ireland/Energy-in-Ireland-1990-2015.pdf
- http://www.seai.ie/Your_Building/BER/
- http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf
- *https://www.nsai.ie/Our-Services-(1)/Agrement/SR-54-Launch/SR-54-workshop-JR.aspx*