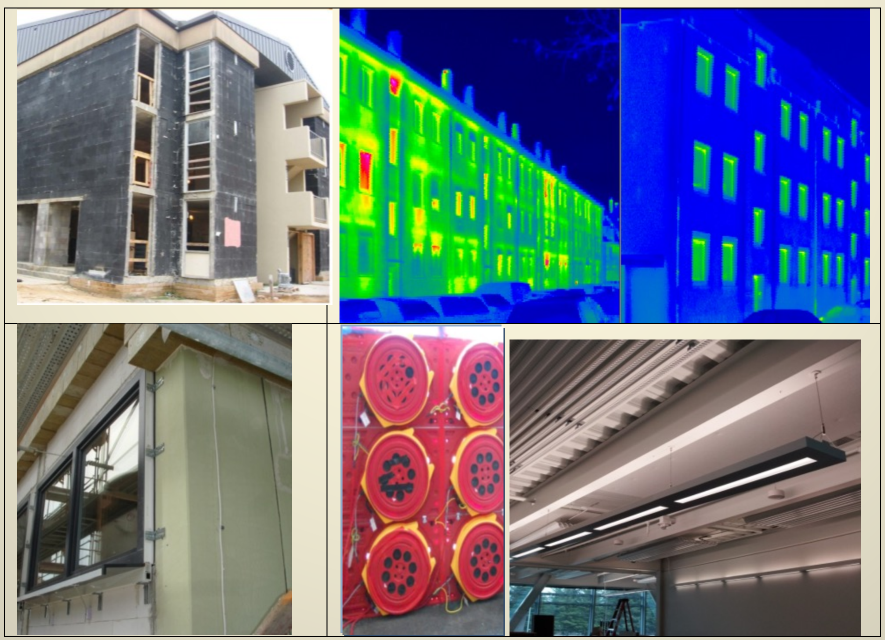
EBC

Energy in Buildings and Communities Programme

Annex 61 Business and Technical Concepts for Deep Energy Retrofits of Public Buildings

Deep Energy Retrofit

A Prescriptive Guide to Achieve Significant Energy Use Reduction with Major Renovation Projects



Subtask A

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Objectives

- Provide guidance on **core technologies bundle** for DER, focusing on building envelope ECMs, lighting systems, and HVAC systems
- **Technology Characteristics** (e.g., U-values, building and duct air tightness, illumination levels and LPD, etc.)
- **Critical design, construction requirements and recommendations** (how-to and how-not-to)
- **Important architectural details and pictures** for
  - Wall cross-sections
  - BE elements connections
  - Continuous air barrier
  - Thermal bridge remediation
- **Outline Quality Assurance Process**

Subtask A: DER Guide - Outline

- Introduction
- What is Deep Energy Retrofit
- Energy efficiency technologies and strategies
- Major renovation and DER
- Deep vs. Shallow Energy Retrofit
- Core bundle of technologies to achieve DER
  - Thermal insulation
  - Thermal bridges
  - Windows
  - Air Barrier requirements
  - Water Vapor Control
  - Lighting systems
  - HVAC systems: core requirements to energy efficiency of equipment, HR, ducts, and pipes

DER Guide – Outline (Cont)

- **Appendices**
  A. Building envelope optimization through modeling
  B. Insulation Materials
  C. Installation of insulation
  D. Remediation of thermal bridges: sequencing and catalogues of architectural details
  E. Window installation guidance
  F. Air barrier – examples of good practices
  G. Lighting design guide
  H. Quality assurance
  J. Economics of DER
- **Conclusions**
- **References**

Definition of DER

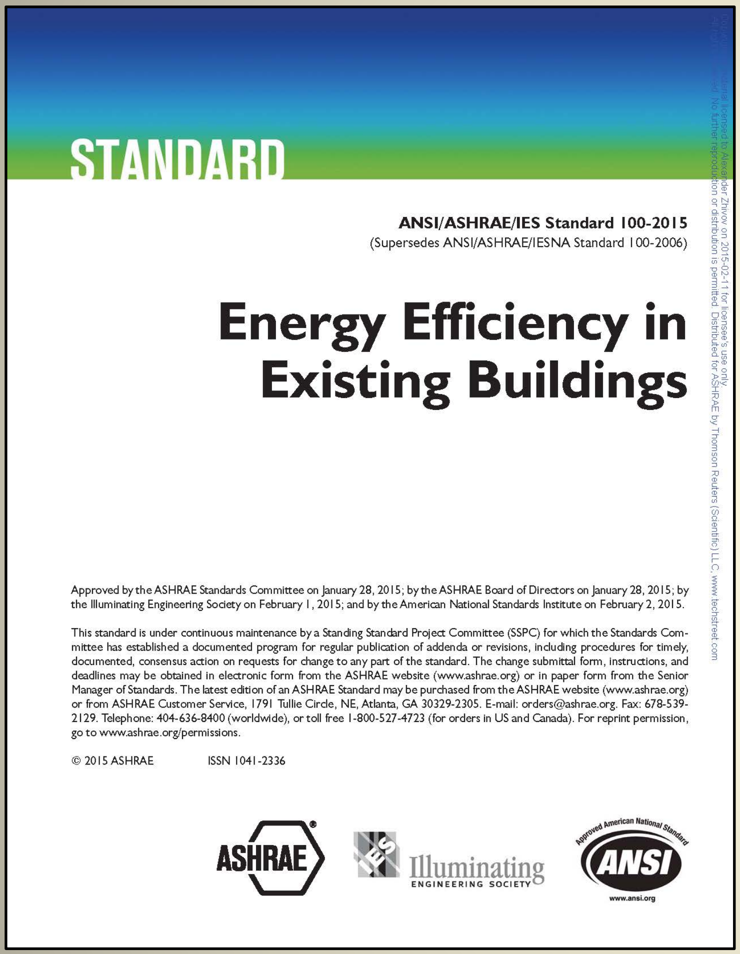
Based on experiences described above, the IEA EBC Annex 61 team has proposed the following definition of the Deep Energy Retrofit:

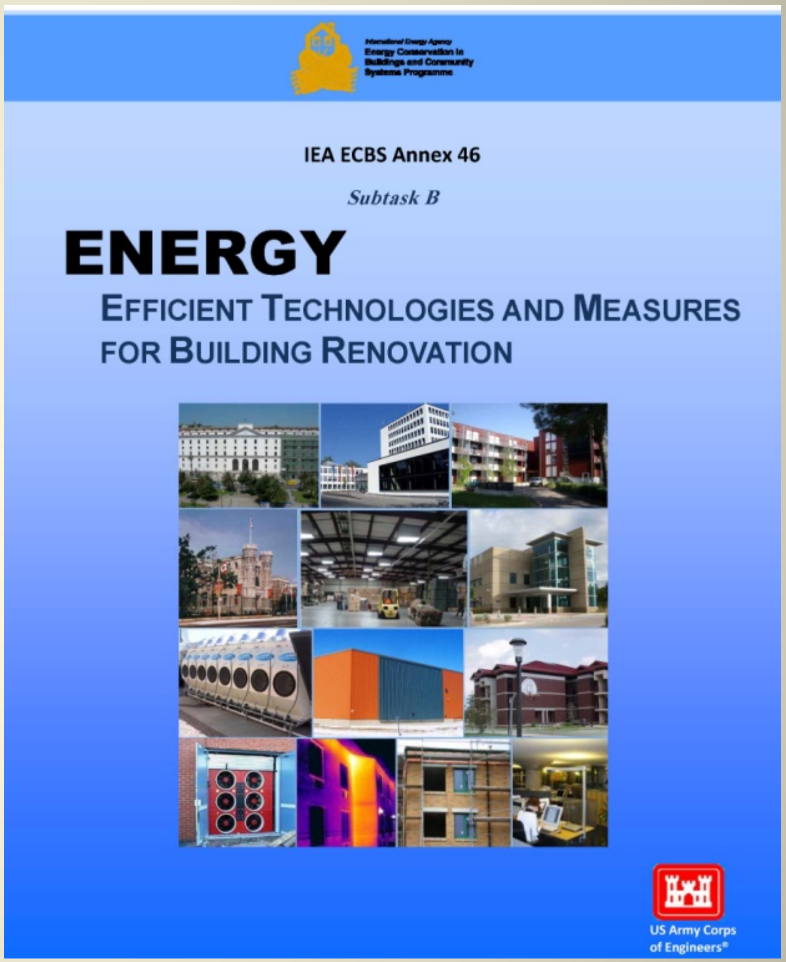
Deep Energy Retrofit (DER) is a major building renovation project in which site energy use intensity (including plug loads) has been reduced by at least 50% from the pre-renovation baseline with a corresponding improvement in indoor environmental quality and comfort.

Core Technologies Bundle

Category	Name	Specification
Building Envelope	Roof insulation	Level defined through modeling
	Wall insulation	Level defined through modeling
	Slab Insulation	Level defined through modeling
	Windows	Parameters defined through modeling
	Doors	National Standards
	Thermal bridges remediation	Guide, main text, and Appendix D
	Air tightness	0.15 cfm/ft^2 (for USA)
	Vapor Control	Guide, main text
	QA	Guide, Appendix J
Lighting and Electrical Systems	Lighting design , technologies and controls	Guide, Appendix G
	Advanced plug loads, smart power strips and process equipment	TopTen (Europe), Top Tier EnergyStar, FEMP Designated, etc.
HVAC	High performance motors, fans, furnaces, chillers, boilers, etc	ASHRAE Std 90.1 2013 and EPBD
	DOAS	Guide, main text
	HR (dry and wet)	Guide, main text
	Duct insulation	EPBD requirements
	Duct airtightness	ASHRAE Handbook and EPBD requirements (Class C ductwork)
	Pipe insulation	EPBD requirements

+ more than 400 other EEMs

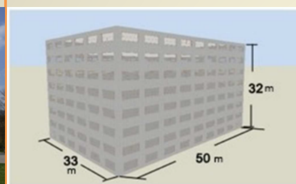
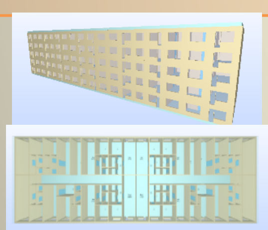
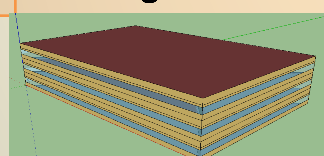
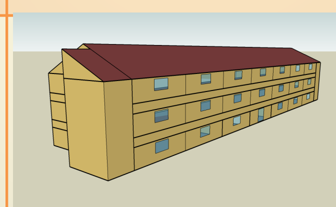
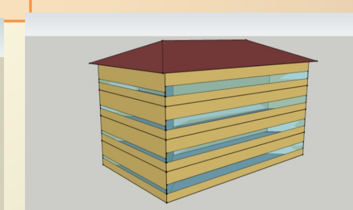
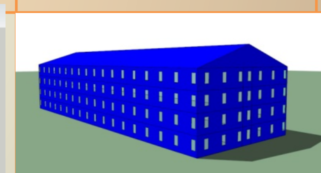




Modelled Scenarios

- Scenario 1 - Baseline: pre-1980 standard to describe the building envelope and systems. Building use and systems operation schedules as well as appliances and their use in W/m^2, used in Scenario 1, have been kept the same for all scenarios, although it is likely that they will be improved/reduced over time;
- Scenario 2 – Business as usual (the base case) – building improvement to meet minimum current standards (usually related to energy efficiency of fans, motors, chillers, furnaces, lighting fixtures, etc.)
- Scenario 3 – Optimize characteristics of the core technology bundle, which will result in 50% energy use reduction against the baseline or achieving current national minimum building energy use requirement for existing buildings
- Scenario 4 – Optimize characteristics of the core technology bundle to achieve the current national dream energy use intensity levels in the renovated building (e.g., passive house requirement).

Building Models Used by the Annex 61 Modeling Team

Austria, AEE	**China, Chongqing University**	**Denmark, Building Research Institute, SBi**	**Estonia, TTU**	**Germany, KEA** **Germany, PHI**
				
Dormitory, c.z. 4A and 7	Office, c.z. 2a, 3a, 3c, 4a, 7	School, c.z. 5A	Public housing, c.z. 6A	Office, c.z. 5A
Latvia, RTU	**UK, University of Reading**	**U.S.A. ERDC-CERL**	**U.S.A., ERDC-CERL**	**U.S.A., ME Group**
				
Dormitory, c.z. 6A	Administrative, c.z. 4A, 5A	Barracks, c.z. 1-8	Office, c.z. 1-8	Dormitory, c.z. 5B

Representative Locations and Climates

Country	Climate zone(s)	Representative City
Austria	4a and 7	Wien, Obertauren
China	2a, 3a, 3c, 4a, 7	Guangzhou , Shanghai, Kunming Beijing, Harbin
Denmark	5a	Copenhagen
Estonia	6a	Tartu
Germany	5a	Wurzburg
Latvia	6a	Riga
UK	4a, 5a	London, Aberdeen
USA	1a-8b	Miami, Houston, Phoenix, Memphis, El Paso, San Francisco, Baltimore, Albuquerque, Seattle, Chicago, Colorado Springs, Burlington, Helena, Duluth, Fairbanks

Building Envelope Section of the Guide

The BE Guide will address the following wall structures:

- CMU or concrete wall with interior insulation
- CMU or concrete wall with exterior insulation
- Steel stud infill wall in steel or concrete
- Steel tube blast-resistant curtain wall perimeter
- Precast sandwich panel.

• Historical Buildings w/interior insulation

• The Guide will address the following roof structures:

- Flat roofs (concrete slabs and steel deck)
- Sloped roofs (metal and wood frame).

Current National Standards for Renovation Projects

Country	Building Energy	Building Envelope	HVAC	Lighting
Austria	OIB Directive Nr.6	OIB RL 6, 2011	EN 1507, EN 12237 ÖNORM H 5057, OIB RL 6, 2011	EN 12464-1 and -2 EN 15193
China	GB 50189-2015	GB 50189-2015, GB/T 7016-2008	GB 50736-2012 GB 50189-2015	GB 50034-2013 GB 50189-2015
Denmark	Danish Building Regulation 2010 DS Standard 418	Danish Building Regulation 2010	Standard 447 Standard 452	DS/EN ISO 12464-1
Estonia	Ordinance No. 63. RT I, 18.10.2012, 1, 2012; Ordinance No. 68. RT I, 05.09.2012, 4, 2012	EVS-EN ISO 10077, EVS-EN 1026 EVS-EN 12207 EVS-EN 12208	EVS-EN 13779, EN 12237 Ordinance No. 70. RT I, 09.11.2012, 12	Ordinance No. 70. RT I, 09.11.2012, 12
Germany	DIN 18599- 1; EnEV 2014	EnEV 2014, DIN 18361 DIN 18355, DIN V 18599/2 DIN 4102, DIN 4108 DIN EN 13162, DIN EN 13163 DIN EN 13164, DIN EN 13165 DIN EN 13167, DIN EN 13171	EnEV 2014, DIN V 18599 DIN 1946- 6, DIN EN 13779 DIN 24192 II/III/IV DIN 4108- 6, DIN 4701- 10,	DIN 18599- 4, DIN 5035 T 1- 14
Latvia	Law On the Energy Performance of Buildings; Cabinet Regulation No. 348; Cabinet Regulation No. 383; Cabinet Regulation No. 382.	Latvian Construction Standard LBN 002-01	Latvian Construction Standard LBN 231-03 Latvian Construction Standard LBN 003-01	Cabinet Regulation No. 359-
UK	BS EN 15603:2008	Building Regulations 2010- Conservation of Fuel and Power: Part L. Scottish Building Standards 2015-Technical Handbook 2015.	Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland: 2015 BS EN 15727:2010 BS 5422:2009	BS EN 12464-1:2011 Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland:2015
USA	ASHRAE Std 90.1 2010 ASHRAE Std 100 2015	ASHRAE Std 90.1 2010	ASHRAE Std 90.1 2010	ASHRAE Std 90.1 +IESNA

Airtightness Best Practice Requirements

Country	Source	Requirement	cfm/ft^2 @ 75Pa*
Estonia	Ordinance No. 58. RT I, 09.06.2015, 21, 2015	≤6 $m^3/(h \cdot m^2)$ @ 50Pa for renovation ≤3 $m^3/(h \cdot m^2)$ @ 50Pa for new construction	**0.42** **0.21**
Austria	OIB RL 6, 2011 for buildings with mechanical ventilation	1.5 1/h at 50 Pa	**0.28**
Denmark	Danish Building Regulations BR10	1.5 1/h at 50 Pa	**0.28**
Germany	DIN 4108-2	1.5 1/h at 50 Pa	**0.28**
USA	USACE ECB for all buildings [21], ASHRAE Standard 189.1-2011, 2013 Supplement, ASHRAE Standard 189.1.–2013 Supplement, ASHRAE Standard 90.1 - 2013		**0.25**
	USACE HP Buildings and DER proposed requirement		**0.15**
Latvia	Latvian Construction Standard LBN 002-01 for buildings with mechanical ventilation	2 $m^3/(m^2h)$ at 50 Pa	**0.14**
UK	ATTMA-TSL2	2 $m^3/h/m^2$ at 50 Pa	**0.14**
CAN	R-2000	1 sq in EqLA @10 Pa /100 sq ft	**0.13**
Germany	Passive House Std	0.6 1/h at 50 Pa	**0.11**

*Based on example for four-story building, 120 x 110 ft, n=0.65. [12]

Modeling Results: Wall Insulation

Country	U-value W/(m^2*K) (Btu/(hr*ft^2*°F)	R-value (m^2*K)/W (hr*ft^2*°F)/Btu
Austria (c.z. 5A) c.z.7	0.135 (0.024) 0.24 (0.043)	7.4. (42) 4.17 (23)
China c.z. 7 c.z. 4A c.z. 3A c.z. 2A c.z. 3C	0.31(0.054) 0.48(0.084) 0.60(0.106) 0.96(0.169) 0.96(0.169)	3.2(19) 2.1(12) 1.7(9) 1.0(6) 1.0(6)
Denmark (c.z. 5A)	0.15 (0.026)	6.7 (38)
Estonia (c.z. 6A)	0.17 (0.03)	5.9 (33)
Germany (c.z. 5A)	0.17(0.03)	4.2 (33)
Latvia (c.z. 6A)	0.19 (0.033)	5.3 (30)
UK (c.z. 4A) 5A	0.22(0.039) 0.22(0.039)	4.5(26) 4.5(26)
USA c.z. 1 c.z. 2 c.z. 3 c.z. 4 c.z. 5 c.z. 6 c.z. 7 c.z. 8	0.76 (0.133) 0.38 (0.067) 0.28 (0.050) 0.23 (0.040) 0.19 (0.033) 0.14 (0.025) 0.11 (0.020) 0.11 (0.020)	1.3 (8) 2.6. (15) 3.6 (20) 4.3 (25) 5.3. (30) 7.1. (40) 9.1 (50) 9.1 (50)

Modeling Results: Roof Insulation

Country	Climate zone	U-value W/(m²*K) (Btu/(hr*ft²*°F)	R-value (m²*K)/W (hr*ft²*°F)/Btu
Austria	7	0.159 (0.028)	6.3 (36)
	4A	0.23 (0.041)	4.4 (25)
China	2a	0.53 (0.093)	1.9(11)
	3a	0.53 (0.093)	1.9(11)
	3c	0.53 (0.093)	1.9(11)
	4a	0.38(0.067)	2.6(15)
	7	0.30 (0.053)	3.3(19)
Denmark	5a	0.10 (0.018)	1 (57)
Estonia	6a	0.11 (0.02)	9.1 (52)
Germany	5a	0.2 (0.035)	5.0(29)
Latvia	6a	0.16 (0.029)	6.3 (35)
UK	4a	0.13(0.023)	7.7 (44)
	5a	0.13(0.023)	7.7 (44)
USA	1	0.16 (0.029)	6.3 (35)
	2	0.14 (0.025)	7.1 (40)
	3	0.12 (0.022)	8.3 (45)
	4	0.12 (0.022)	8.3 (45)
	5	0.11 (0.020)	9.1 (50)
	6	0.09 (0.0167)	11.1 (60)
	7	0.09 (0.0154)	11.1 (65)
	8	0.08 (0.0133)	12.5 (75)

Modeling Results: Windows

Country	U-value W/(m²*K) (Btu/(hr*ft²*°F)	R-value (m²*K)/W (hr*ft²*°F)/Btu	SHGC
Austria (c.z. 5A) c.z.7	1.09 (0.19) 1.09 (0.19)	0.92 (5.3) 0.92 (5.3)	0.60 0.60
China c.z. 2A c.z. 3a c.z. 3C c.z. 4A c.z. 7	 2.55(0.45) 2.55(0.45) 2.70(0.48) 1.79(0.32) 1.79(0.32)	 0.39 (2.2) 0.39 (2.2) 0.37 (2.1) 0.56 (3.1) 0.56 (3.1)	 0.48 0.48 0.48 0.68 0.68
Denmark (c.z. 5A)	1.2 (0.21)	0.83 (4.8)	0.63
Estonia (c.z. 6A)	1.1 (0.19)	0.91 (5.3)	0.56
Germany (c.z. 5A)	1.3 (0.23)	0.77 (4.3)	0.55
Latvia (c.z. 6A)	1.2 (0.21)	0.83 (4.8)	0.43
UK (c.z. 4A) c.z. 5A	1.32 (0.23) 1.79 (0.32)	0.76 (4.3) 0.56 (3.1)	0.48 0.68
USA c.z. 1&2 c.z. 3&4 c.z. 5 c.z. 6 c.z. 7 c.z. 8	1.98 (< 0.35) 1.70 (< 0.30) 1.53 (< 0.27) 1.36 (< 0.24) 1.25 (< 0.22) 1.02 (< 0.18)	> 0.51 (2.9) > 0.59 (3.3) > 0.65 (3.7) > 0.74 (4.2) > 0.80 (4.5) > 0.98 (5.6)	< 0.25 0.30- 0.35 0.35- 0.40 >50 >50 >50

Site and Source Energy Use Reduction for DER Projects Using Core Bundles of Technologies and Beyond

Climate Zone	Baseline			Base Case		DER			HPB	
	Total site EUI (100%) kWh/m2yr (kBtu/ft2 yr)	Site EUI for heating (100%) kWh/m2 yr (kBtu/ft2 yr)	Source EUIt, (100%) kWh/m2 yr (kBtu/ft2 yr)	Site energy use reduction, %	Source energy reduction ,%	Site energy use reduction,%	Site heating energy use reduction, %	Source energy use reduction, %	Site energy use reduction, %	Source energy reduction, %
Public Housing, Austria										
5A	218 (69)	152 (48)	210 (67)	38	31	**50**	73	64	55	68
7	253 (80)	184 (58)	235 (75)	47	36	**50**	68	62	55	68
Office Building, China										
2A	3(1)	105(33)	331(105)	37	37	**47**	56	47	54	54
3A	25(8)	119(38)	378(120)	38	38	**51**	62	51	65	65
3C	8(3)	77(24)	243(77)	36	36	**47**	64	47	69	69
4A	117(37)	201(64)	393(125)	42	42	**53**	71	41	62	55
7	239(76)	306(97)	472(150)	32	33	**50**	62	38	67	59
School Building, Denmark										
6A	252 (80)	210 (67)	314 (99)	19	16	**56**	67	45	82	63
Dormitory, Estonia										
6A	153 (49)	213 (68)	225 (71)	29	22	**47**	69	37	70	58
Office Building, Germany										
5A	256 (81)	220 (70)	307 (97)	40	27	**55**	58	53	81	76
Office Building, UK										
4A	89(28)	155(49)	291(92)	20	16	**51**	84	32	58	42
5A	135(43)	201(64)	341(108)	23	20	**60**	83	42	67	52

Site and Source Energy Use Reduction for DER Projects Using Core Bundles of Technologies

Climate Zone	Baseline			Base Case		DER			HPB	
	Total site EUI (100%) kWh/m2yr (kBtu/ft2 yr)	Site EUI for heating (100%) kWh/m2 yr (kBtu/ft2 yr)	Source EUIt, (100%) kWh/m2 yr (kBtu/ft2 yr)	Site energy use reduction, %	Source energy reduction ,%	Site energy use reduction,%	Site heating energy use reduction, %	Source energy use reduction, %	Site energy use reduction, %	Source energy reduction, %
Barracks, USA										
1A	1 (0)	398 (126)	1154 (366)	17	19	**39**	59	42	59	59
2A	33 (10)	380 (121)	1025 (325)	17	18	**41**	84	42	60	59
2B	17(5)	365 (116)	1008 (320)	17	18	**40**	80	42	61	61
3A	65 (21)	394 (125)	965 (306)	19	18	**45**	84	42	63	59
3B	37 (12)	326 (103)	812 (258)	15	14	**39**	82	37	60	57
3C	35 (11)	273 (87)	634 (201)	12	9	**33**	70	31	46	37
4A	103 (33)	397 (126)	869 (276)	20	16	**48**	85	25	65	59
4B	86 (27)	333 (106)	745 (236)	16	12	**42**	88	35	62	56
4C	111 (35)	330 (105)	678 (215)	18	12	**44**	86	35	62	55
5A	160 (51)	422 (134)	872 (277)	21	17	**51**	87	42	67	60
5B	133 (42)	362 (115)	733 (233)	18	13	**52**	88	37	65	57
6A	212 (67)	448 (142)	839 (266)	22	16	**55**	88	44	70	61
6B	192 (61)	414 (131)	773 (245)	21	14	**53**	89	41	69	60
7	283 (90)	508 (161)	878 (279)	24	18	**59**	88	47	73	63
8	417 (132)	630 (200)	978 (310)	24	18	**64**	92	52	77	67
Office Building, USA										
1A	24(7)	261 (83)	815 (259)	30	27	**48**	91	45	66	64
2A	60 (19)	285 (90)	814 (258)	32	28	**46**	63	43	70	65
2B	81 (26)	314 (100)	862 (273)	36	29	**49**	87	41	73	91
3A	82 (26)	288 (91)	771 (245)	34	28	**47**	63	43	71	64
3B	68 (22)	251 (80)	680 (216)	30	23	**51**	92	41	66	58
3C	45 (14)	183 (58)	507 (161)	26	16	**41**	96	30	59	51
4A	96 (30)	271 (86)	685 (217)	35	26	**50**	89	38	69	60
4B	71 (22)	227 (72)	593 (188)	31	21	**50**	95	37	63	54
4C	76 (24)	206 (65)	513 (163)	31	18	**48**	96	33	63	52
5A	107 (34)	270 (86)	656 (208)	35	25	**50**	87	37	69	58

DER of Dining Facilities Vs. HPB Renovation (with an improvement of internal processes)

Climate Zone	Baseline			Base Case		DER			HPB	
	Site EUIh kWh/m² yr (kBtu/sq ft yr)	Site EUIt kWh/m² yr (kBtu/sq ft yr)	Source EUIt kWh/m² yr (kBtu/sq ft yr)	**Site Energy %**	Source Energy %	**Site Energy %**	Site Heating Energy %	Source Energy %	**Site Energy %**	Source Energy %
1A	29 (9,198)	604 (191)	1616 (512)	**2%**	3%	**15%**	29%	16%	**40%**	40%
2A	147 (46,626)	706 (224)	1687 (535)	**11%**	9%	**22%**	45%	20%	**48%**	36%
2B	111 (35,208)	744 (236)	1897 (601)	**10%**	9%	**22%**	43%	22%	**50%**	40%
3A	307 (97,377)	840 (266)	1766 (560)	**16%**	12%	**17%**	43%	23%	**57%**	45%
3B	201 (63,755)	749 (237)	1704 (540)	**16%**	12%	**26%**	52%	23%	**51%**	42%
3C	196 (62,169)	645 (205)	1371 (434)	**8%**	7%	**26%**	29%	14%	**46%**	32%
4A	459 (145,590)	964 (306)	1832 (581)	**20%**	15%	**30%**	47%	25%	**63%**	43%
4B	333 (105,624)	854 (271)	1753 (556)	**22%**	16%	**30%**	53%	25%	**58%**	45%
4C	434 (137,660)	897 (284)	1665 (528)	**19%**	14%	**27%**	43%	22%	**61%**	44%
5A	572 (181,432)	1071 (340)	1932 (612)	**19%**	17%	**31%**	45%	42%	**67%**	50%
5B	470 (149,079)	972 (308)	1833 (581)	**24%**	18%	**33%**	52%	23%	**64%**	48%
6A	733 (232,500)	1215 (385)	2041 (647)	**21%**	17%	**33%**	45%	28%	**71%**	54%
6B	681 (216,006)	1177 (373)	2035 (645)	**24%**	19%	**35%**	50%	29%	**69%**	53%
7	938 (297,524)	1420 (450)	2257 (715)	**22%**	19%	**36%**	47%	31%	**75%**	58%
8	1376 (436,453)	1863 (590)	2731 (866)	**18%**	17%	**39%**	64%	34%	**82%**	66%

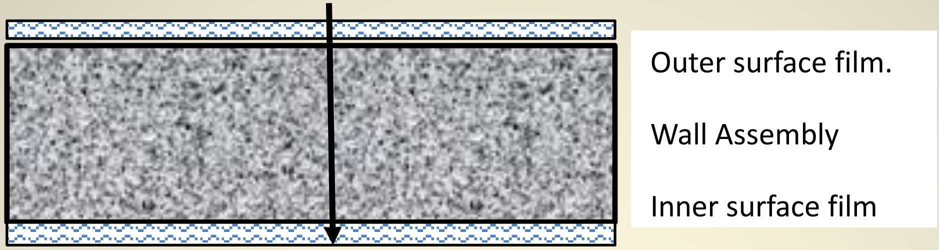
Dining Facilities compared to Barracks and Office Buildings have high ventilation, cooking, and sanitation loads, which make core envelope package much less effective.

Insulation Materials

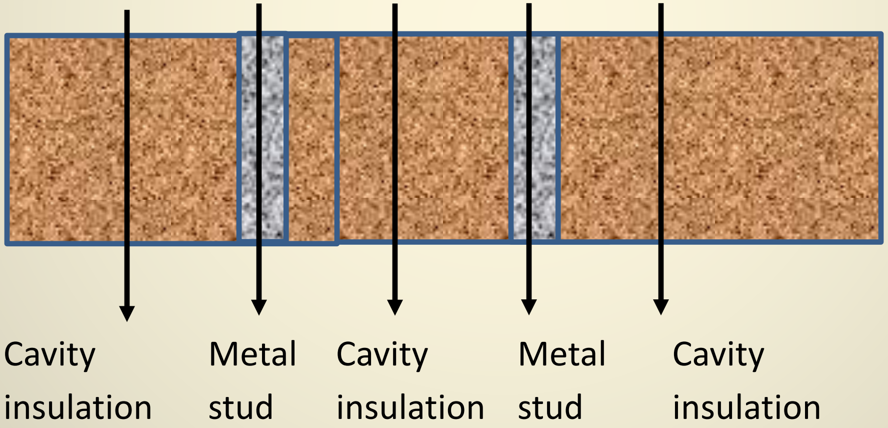
Many insulation material are available on the market today. They differ by their origin, type, thermal conductivity, water vapor
environmental impact, flammability and other factors summarized in the Table below.

Picture	Name of Material	Origin	Thermal conductance W/(m K)	Water vapor diffusion resistance factor (μ)	Vapor Permeance (perm-inch)	Fire behavior	Approximate cost, Eu/m2 **Will be developed under assumption of U=0,2**	Assembly type	Health hazard protection requirements
Eurema 	Stonewool (mineral wool)	Mineral	0.035-0.045	1	30+	Incom-bustible, meltingpoint		Panel, roll	Dust protection for inside
 Eurema	Glasswool (mineral wool)	Mineral							
	Ultimate (mineral wool)	Mineral							
	Expanded polystyrene (EPS)	Synthetic							
	Graphit embedded EPS	Synthetic							
	Extruded polystyrene (XPS)	Synthetic							
	Polyurethane (PUR)	Synthetic	0.022-0.040	x		Hardly inflammable			
	Polyisocyan-urat (PIR)	Synthetic	0.023 – 0.028	82 – 10.000		Hardly inflammable			
	Wood fibre	Vegetable	0.040-0.055			Normally inflammable			
	Hemp fibre	Vegetable	0.040- 0.045	1-2		Normally infammable			
	CL Cellulose	Vegetable	0.038-0.069	1-2		Normally inflammable			
	Vacuum insulation panel	Synthetic	0.007	> 1.000.000		Normally inflammable			

Continuous Insulation Requirement



$$R_{\text{cont. insulation}} = R_T - R_i - R_{\text{exiting assembly}} - R_o$$



$$U_{av} = aU_a + bU_b + \ldots + nU_n$$

Internal Vs External Insulation

Factor	**Interior insulation**	**Exterior insulation**
Design exterior	No changes	Normally big changes to appearance
Design interior	Usable area is reduced	Window reveal lining becomes deeper
Windows	Position of windows can be maintained best if supplemented with an inner sash and if insulation is added under the reveal lining to reduce the cold bridge	Windows are best moved out in the facade (flush with the additional insulation) to reduce cold bridges.
Roof construction	No change	It might be necessary to modify the overhang, flashings etc.
Cold bridges	A large number of cold bridges where partitions and floors are jointed to the façade and where cavity walls are made with headers rather than wall ties	Cold bridges from the interior are reduced significantly. Cold bridges from cantilevered beams e.g., in balconies are increased
Sensitivity to moisture and workmanship	Very sensitive to moisture related damages	Sensitivity to failures is modest
Nuisance during construction	The work causes many inconveniences for the occupants.	Scaffolding and possibly cover is needed. Work may be rather noisy but re-housing is rarely needed
Other refurbisment works	Can be done together with other interior refurbishment	Especially profitable if combined with necessary refurbishment of facades
Radiators and other interior installations	Must be repositioned where placed on an outer wall	No change

Installation of Insulation Materials

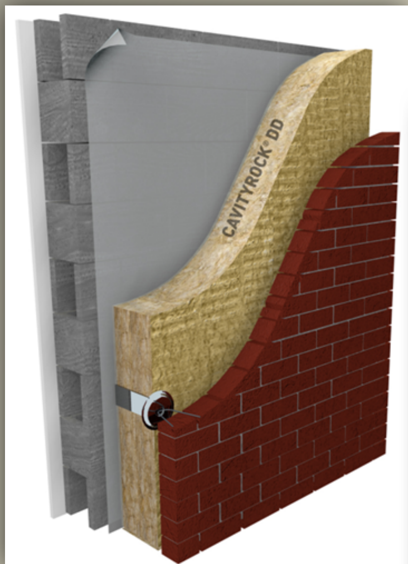
Walls:

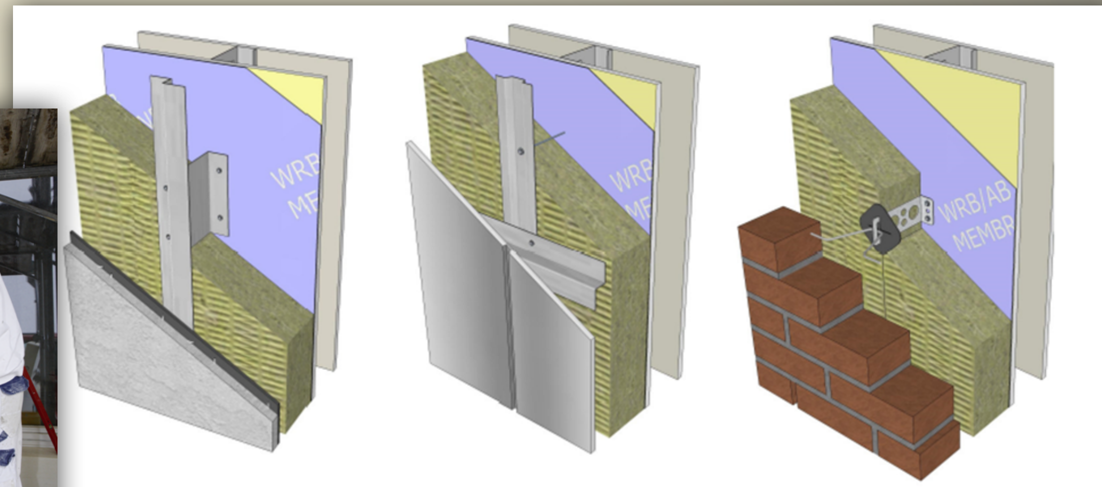
- Cavity wall with brick cladding;
- Cavity wall with glass-fiber reinforced polyester panels;
- Cavity wall with glass-fiber cement panels;
- Cavity wall with sheet metal panels, more often steel than aluminum but both prevalent;
- Precast concrete panels with a wide variety of external finishes;
- Composite panels with insulation bonded or sandwiched between external weathering finish and the internal finish;
- Metal frame walls with a load bearing steel studs. Metal beams may be cased in concrete, plasterboard or sprayed with a coating to insulate it from the heat of the fire or it can be protected by a fire resistant ceiling construction. Bricks, stone, reinforced concrete, architectural glass, and/or sheet metal may be used for the exterior skin of the building.
- Concrete frame walls with a hollow clay tiles or gas concrete blocks infill.
- Wood frame walls. Exterior walls are covered or "sheeted" with Oriented Strand Board, OSB, or Plywood to give them strength. Different siding types are available, e.g., wood, brick, stucco, vinyl, etc.
- Curtain walling, typically involving a secondary frame attached to the main structure with both glazed panels and blank panels held in place by sealants or gaskets.

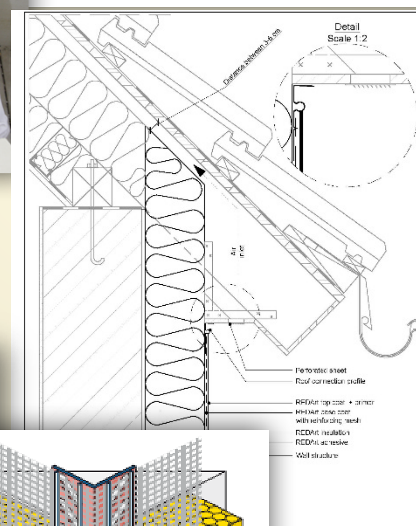
Roofs

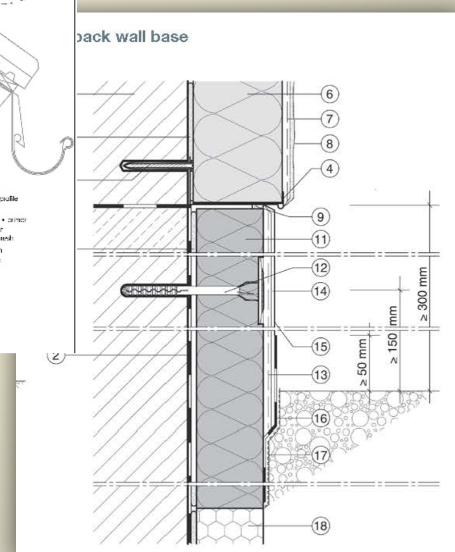
- Flat reinforced concrete slabs;
- Lightweight trusses in timber and steel, supporting a flat concrete slab;
- Pitched roofs of profiled metal sheet panels, or concrete (rarely clay) interlocking tiles;
- Flat roofs in timber with decking and bitumen based felt.

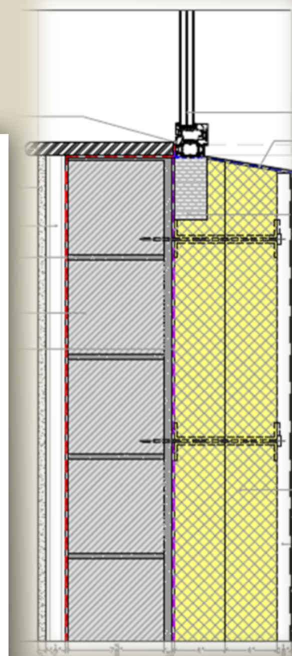
Examples of Wall Insulation Installation

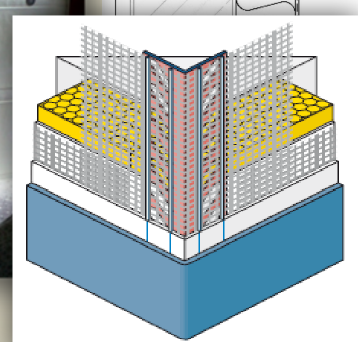




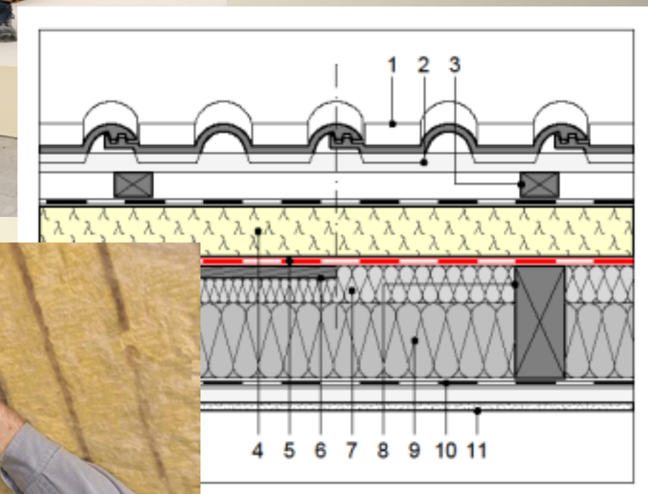




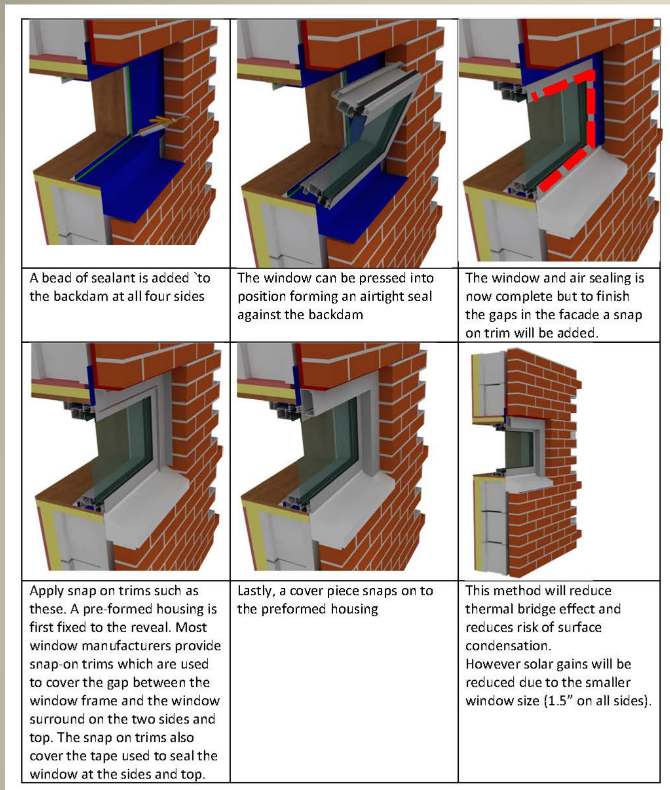


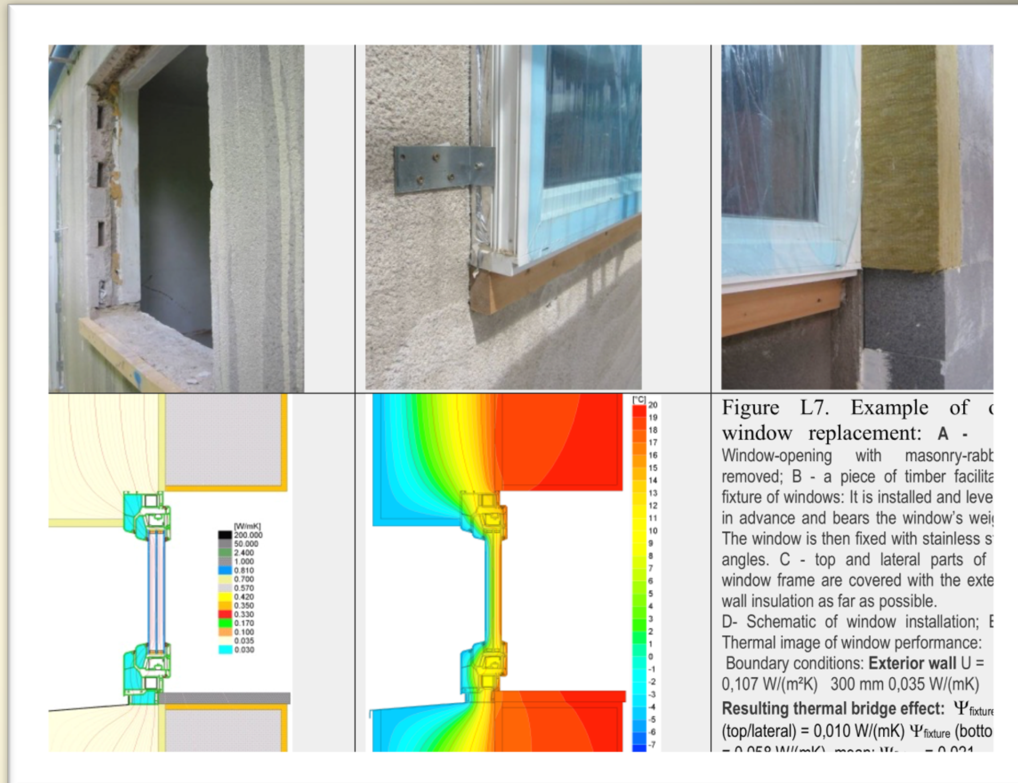


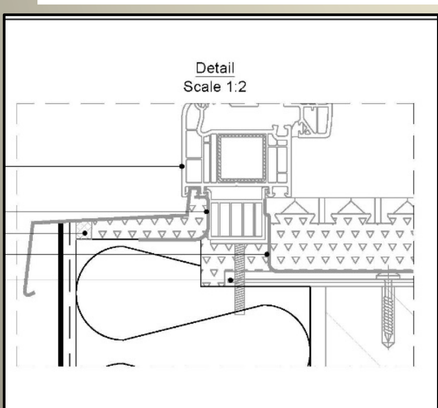
Examples of Roof Insulation Installation

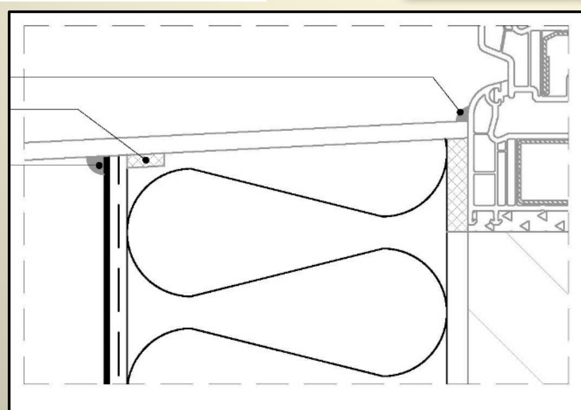


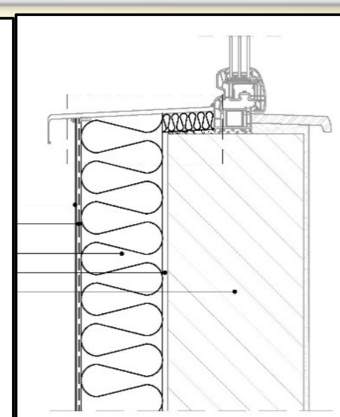
Examples of Window Installation

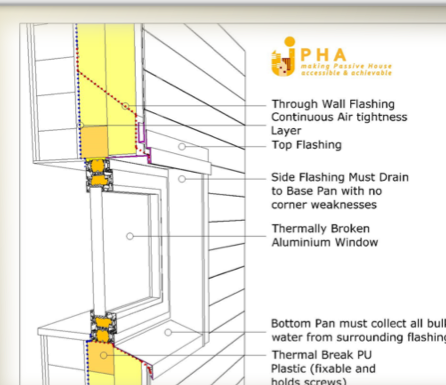




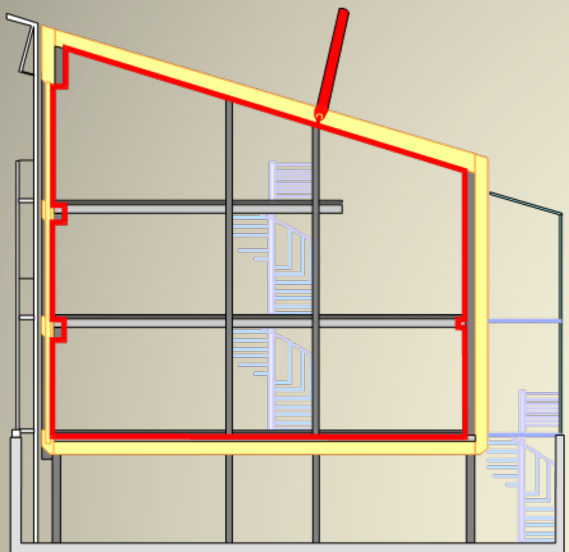


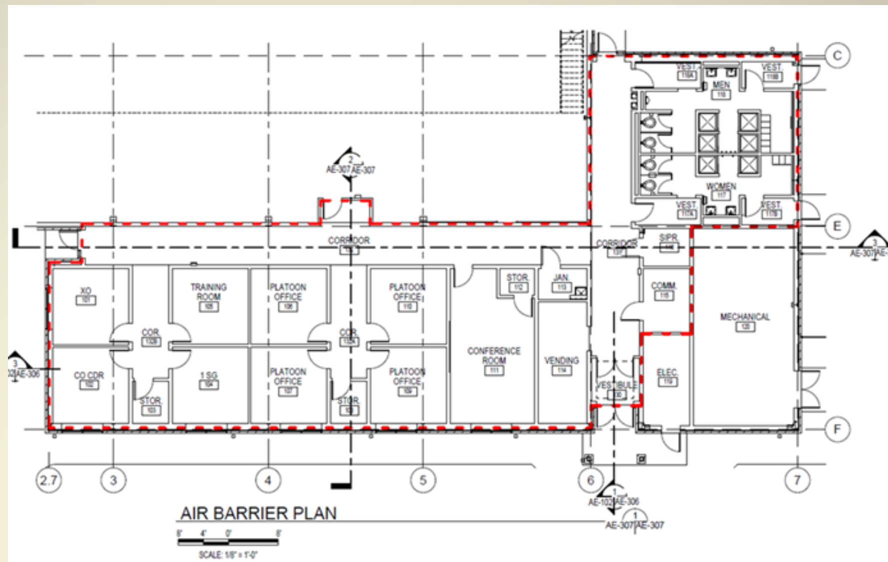


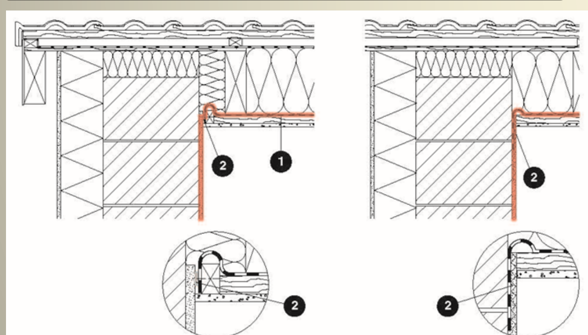


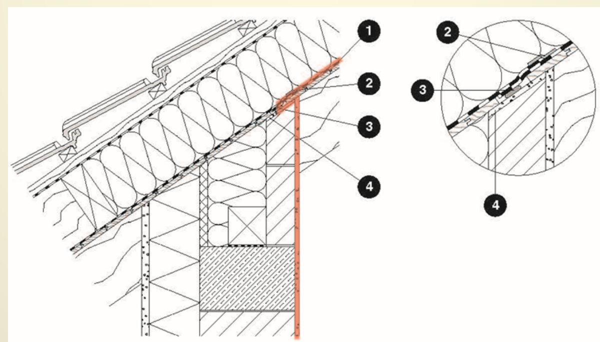


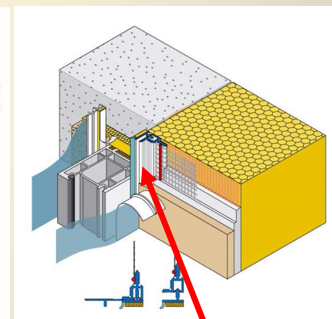
Air Barrier with Major Renovation

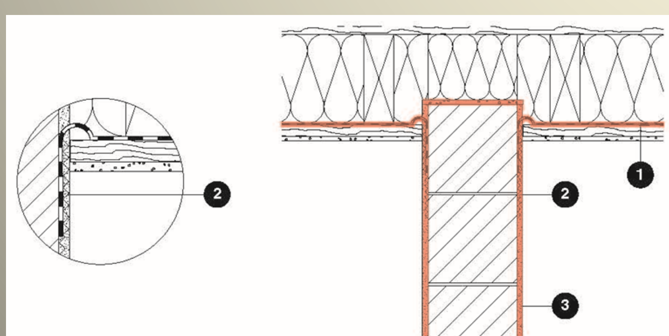


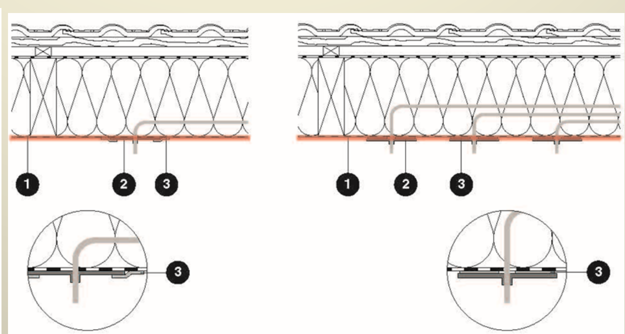




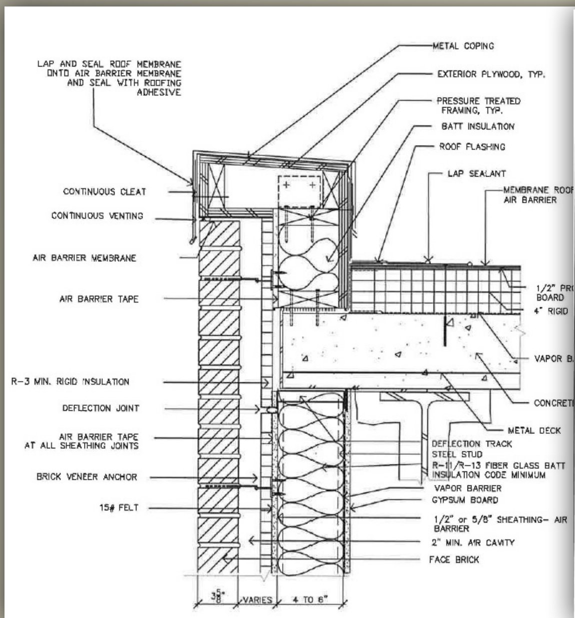


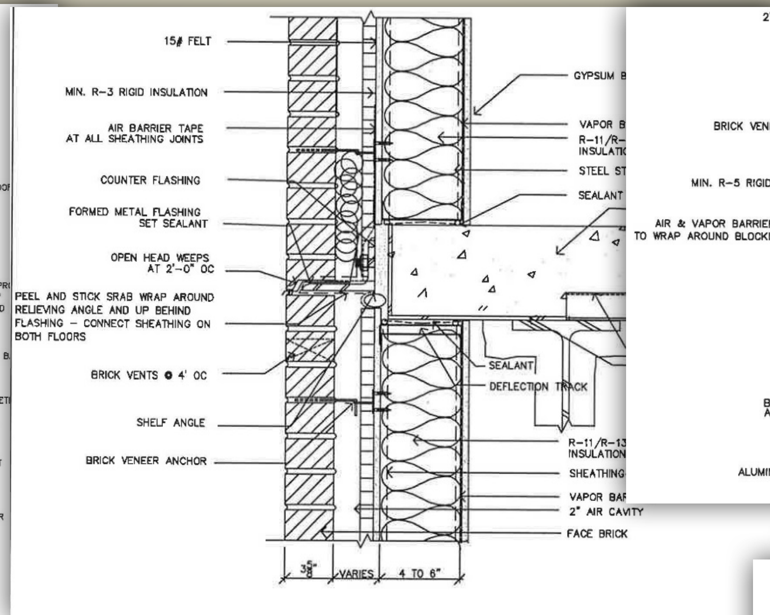


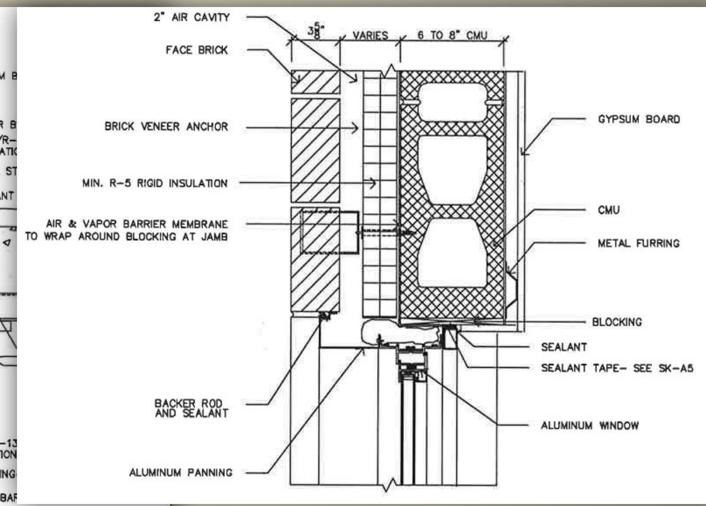


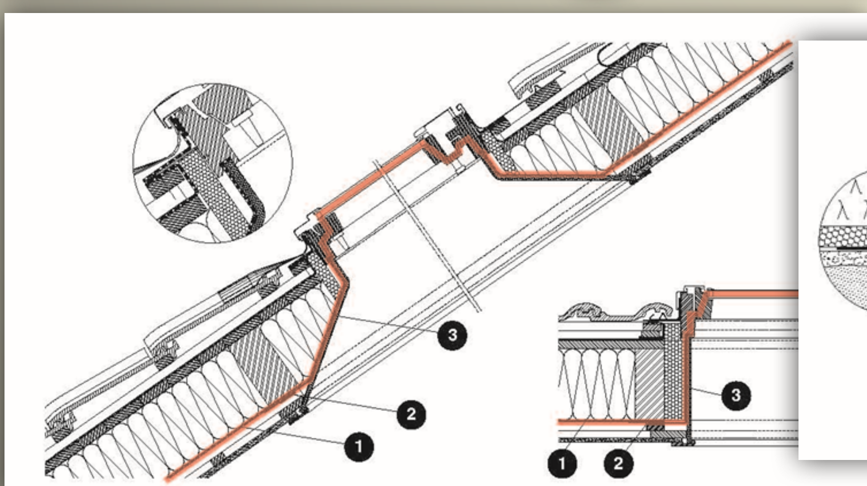


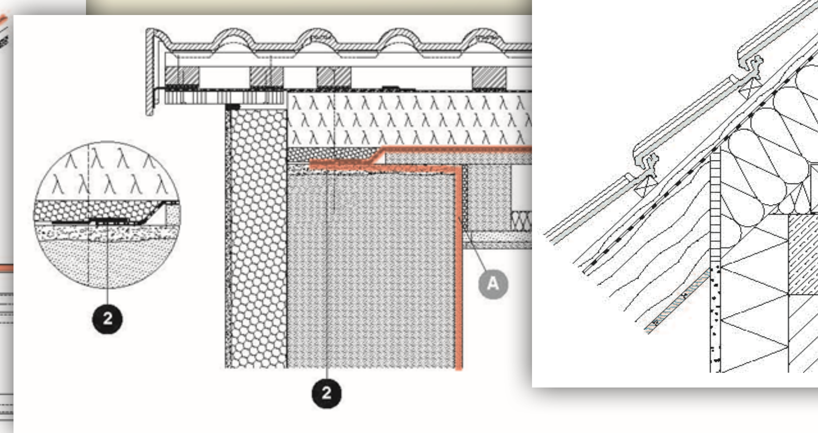
Building Airtightness Improvement (Major Renovation)

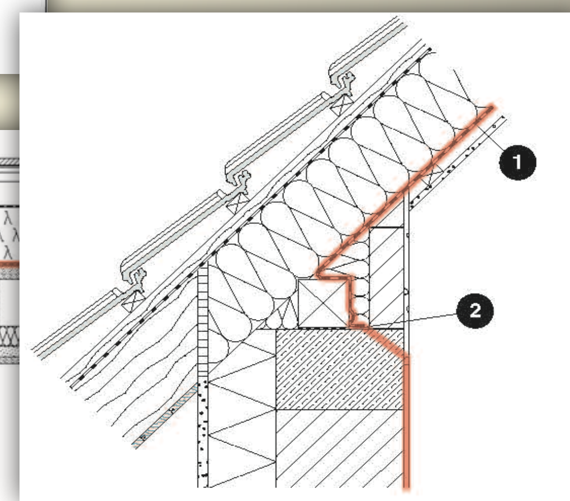




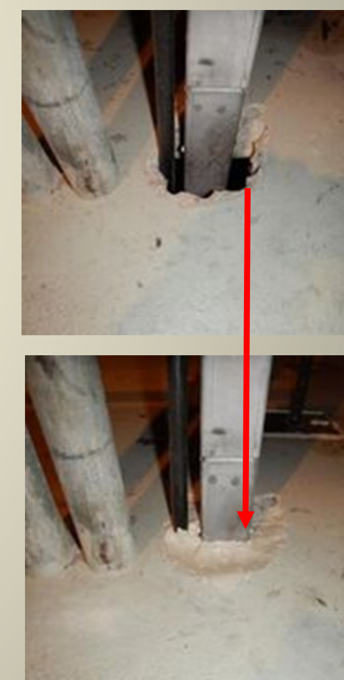


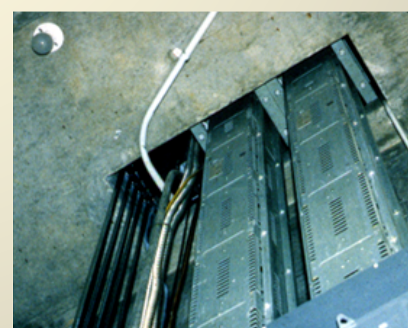




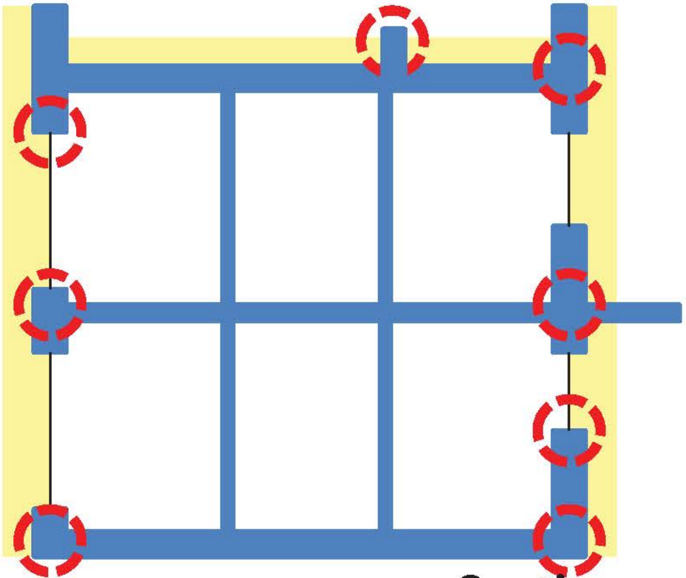


Building Airtightness Improvement (Minor Renovation)

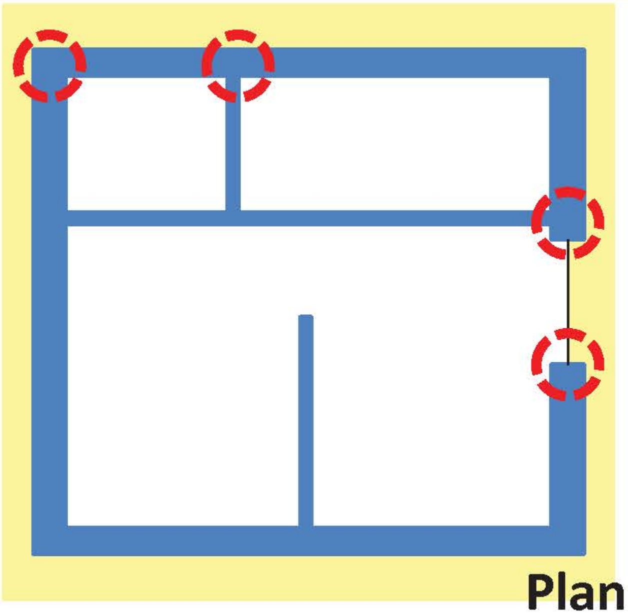




Thermal Bridges



Section



Plan

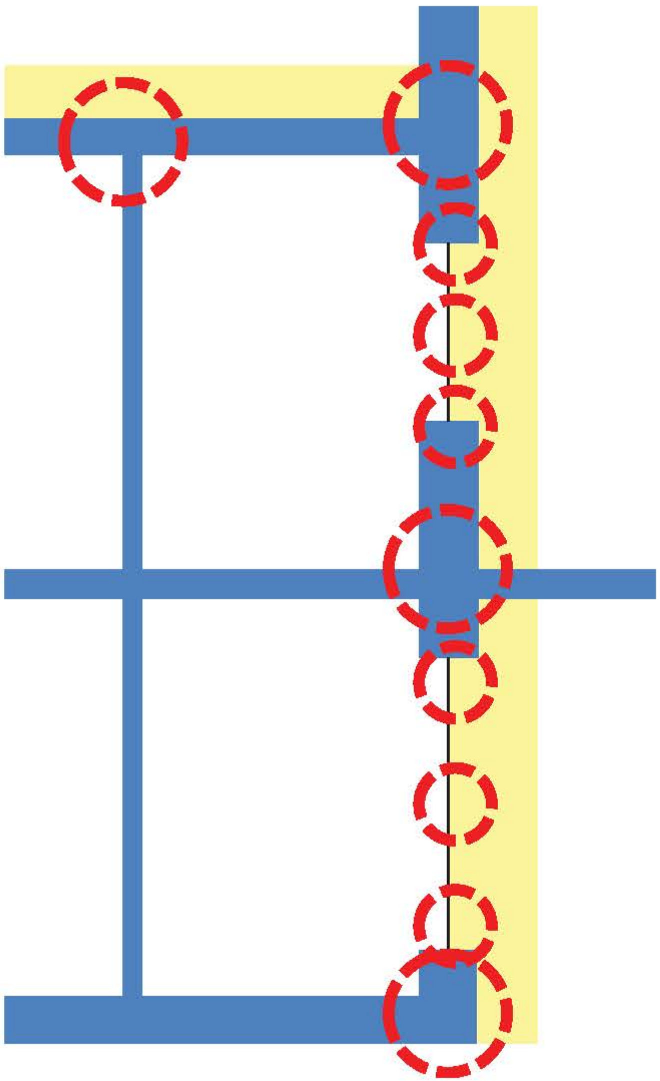
Details of Major Magnitude

1. At Eaves/Ridge
2. Window and Door Fitting – Head, Sill and Jamb
3. At Projections, Shades Or Intermediate Floors
4. Internal Walls to External Walls
5. Intermediate Floors
6. At Grade

Details of Minor Magnitude

1. Wall Corner – Never Usually an Issue
2. Threshold or Door
3. Duct and Service Connections
4. Penetrations at Installations in Roof; PV or Water Tanks

Main Offenders



1. At Eaves/Ridge
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3. At Projections, Shades Or Intermediate Floors
4. Internal Walls to External Walls
5. Intermediate Floors
6. At Grade

Some Architectural Details for Thermal Bridge Mittigration

Wall

1. CMU or concrete wall with interior insulation

a. At grade (stem wall)
b. At suspended slab (w/steel stud or exposed block)
c. At parapet with concrete roof, concrete parapet
d. Steel roof joists at parapet
e. Window jamb
f. Window head
g. Window sill
h. Blast resistant window jamb
i. Door jambs to CMU
j. Thru slab projection eg. shade or balcony

2. CMU or concrete wall with exterior insulation (CMU+2”+brick)

a. Roof parapet with concrete roof
b. Roof parapet with OWSJ + deck
c. At grade transition (stem wall)
d. Window jamb
e. Window head
f. Window sill
g. Blast resistant window jamb
h. Blast resistant window head
i. Suspended slab at shelf angle

3. Steel stud infill wall in steel or concrete frame (SS+2”+brick)

a. Roof parapet with steel frame
b. Window jamb
c. Window head
d. Window sill
e. Steel tube blast-resistant curtainwall perimeter
f. Steel beam penetration

4. Steel building with Insulated Metal Panel

a. Eave Detail

5. Precast sandwich panel

a. Roof of steel joists bearing on inner wythe of sandwich

6. Important Clearwall Details

a. 6” steel studs @16” w/brick ties
b. Horizontal Z-girts on sheathing & steel studs
c. Batten and counter-batten Z-girts on 16” sheathing & steel studs

7. Historical Details w/interior insulation

a. Stone veneer over CMU @ grade or parapet
b. Window sill in solid brick masonry

Examples

2f Window Sill in CMU or Concrete Wall with Exterior Insulation

Notes

After removing the existing brick sill, make the insulation continuous and aligned with the window thermal break- key to the success of this detail is ensuring good structural attachment of the window and the alignment of the window thermal break. This offers chance to improve the window air tightness and rain control performance as well.

Sub-sill flashing is required for rain control. It should posses a raised vertical section at the back (called "backdam"), tall enough allowing the installation of sealant between it and the window (for major both, water and airflow control continuity)

Use metal flashing only to cross part of the insulation and take water to the exterior. Polymeric, self-adhered membranes can be used to connect the water control layer on the face of the wall to the metal flashing.

The hollow space of open window frames will promote natural convective heat flow through it. This undesired heat flow can be reduced by filling these voids with factory-installed custom-shaped foam plastic or rigid stone sections.

To support the outer portion of a window with a single lite so that its thermal break is aligned with wall insulation, the window support should be installed below the IGU.

Existing Window Sill

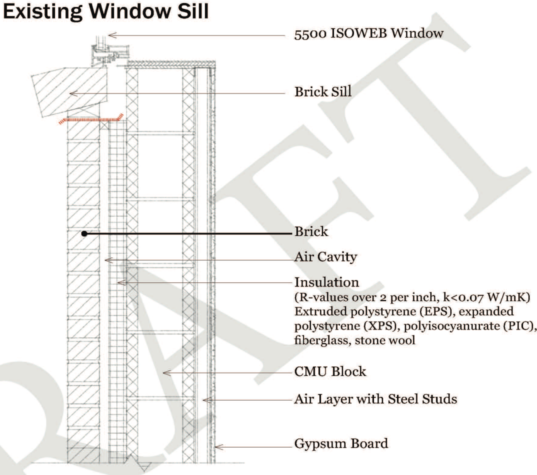
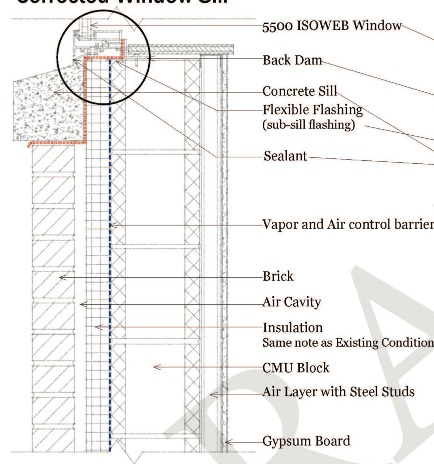


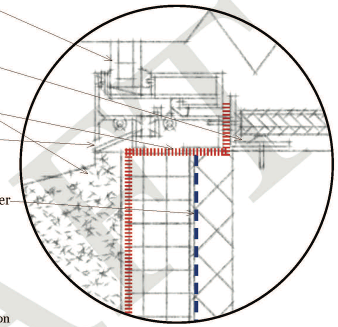
Table of Modeling Values

Component	Thickness Inches (mm)	Conductivity Btu/h • ft • °F (W/m K)	Nominal Resisitance hr·ft²·°F/Btu (m²K/W)	Density lb/ft³ (kg/m³)
Interior Film	-	-	R-0.74 (0.13 RSI)	-
Brick	3 5/8" (92)	0.578 (1)	R-0.523 (0.092 RSI)	110 (1800)
Air Cavity	1" (25)	0.070 (0.122)	R-1.185 (0.209 RSI)	-
Insulation	2" (51)	0.0139 (0.024)	R-11.99 (2.112 RSI)	-
CMU Block	7 5/8" (194)	0.069 (1.2)	R-0.916 (0.161 RSI)	130 (2100)
Air Layer with Steel Studs	1 3/4" (44)	0.2219 (0.384)	R-0.66 (0.116 RSI)	-
Gypsum Board	1/2" (13)	0.092 (0.16)	R-0.5 (0.08 RSI)	50 (800)
5500 ISOWEB WINDOW	-	-	-	-
Aluminum Sill Flashing	12 Gauge	160	-	-
Brick Sill	3 5/8" (92)	0.578 (1)	-	110 (1800)
Exterior Film	-	-	R-0.23 (0.04 RSI)	-

Corrected Window Sill



Close up of the Corrected Window Sill



Thermal Performance

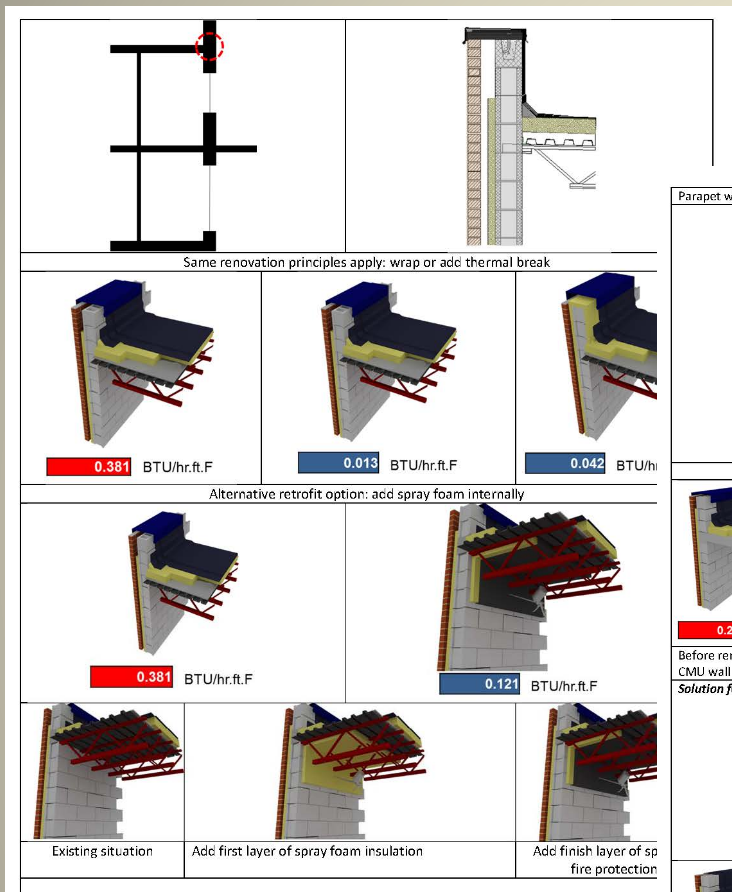
Condition	Clear Wall R-Value (W/m2K)	Linear Transmittance (Ψ) Btu/h • ft • °F (W/mK)
Wall Clear Field	R-15.7 (0.369)	-
Existing Fitting Situation	-	**0.445 (0.771)**
Corrected Fitting Situation	-	**0.017 (0.030)**

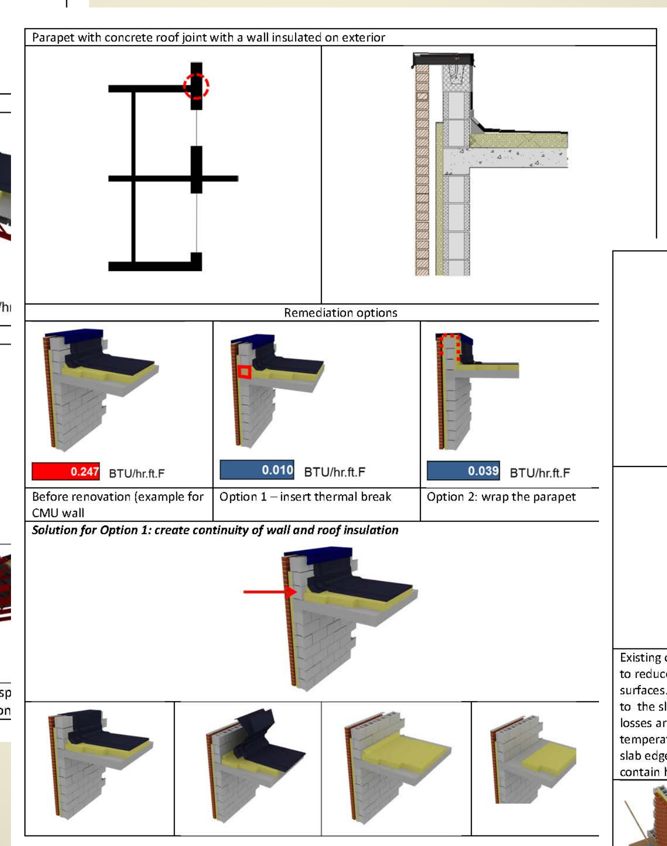
1. Thermal analysis based on 5500 ISOWEB WINDOW- thermally broken window selection.
2. The performance of the correct version can be improved only slightly from Ψ - 0.017 Btu/h•ft•°F using thicker insulation and tweaking the details of the window sill attachment to the window and the alignment of the thermal break.
3. The reported Ψ-value does not include the metal angle backdam or anchors thermal effects.

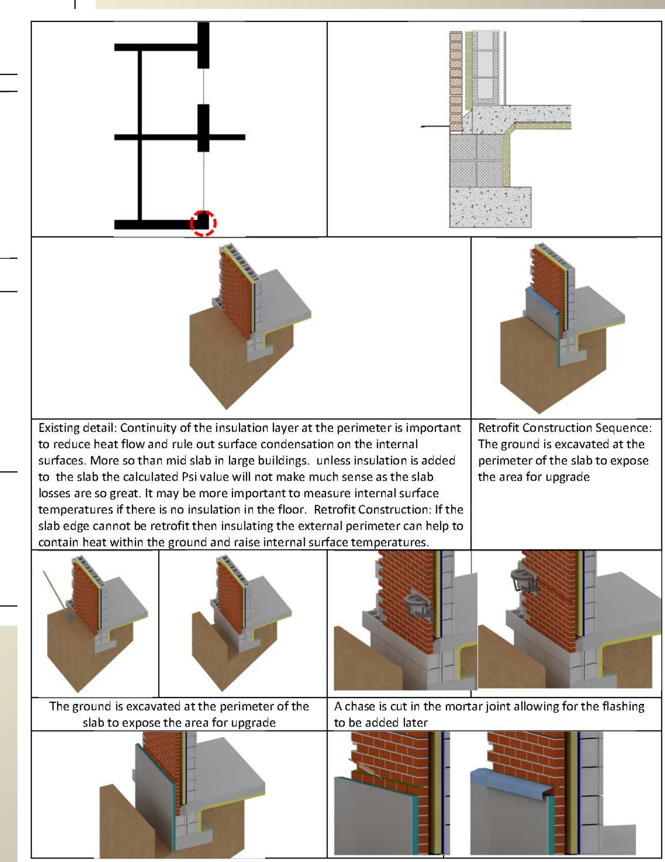
Quality Control/ Sequencing

1. Remove old window
2. Remove brick sill, flashing and window board
3. Insert sheet metal back dam at the top surface where the existing brick sill was laying
4. Insert additional insulation to rear of sill
5. Insert additional Insulation plus wood buck
6. Insert flexible flashing
7. Insert backdam anchor
8. Insert pre-shimmed glazing tape air and water seal, joining the air and moisture barriers with the metal angle backdam and flexible flashing.
9. Insert new brick sill
10. Insert sealant
11. Hinge window into position and brace to backdam anchor
12. Add window board

Thermal Bridges Mitigation Sequencing







Lighting Guide

Lighting Design Guide for Low Energy Buildings – New and Retrofits

Improved Design, required illuminance levels, reduced electrical power:

- hybrid ambient-day lighting,
- combination of ambient-task lighting,
- high efficiency luminaires,
- control strategies

OFFICE (OPEN)

Lighting Technologies	
LAMP L01 Fluor 32WT8 LED **BALLAST/DRIVER** B01 Multi-Level B02 Dimming B04 Program Start	**LUMINAIRE** F03 Non-Planar Lensed Troffer F04 Suspended Direct/Indirect F05 Furniture Integrated F09 or F51 Task F12 Wallwash F40 or F50 Adjustable Accent **CONTROLS** C03 Dual Tech Occ/Vac Sensor C07 Dimming Photosensor C08 Switching Photosensor

Target Illuminance	Target LPD
30-50fc	0.70 W/ft^2

SPACE DESCRIPTION

Open offices are designed to accommodate multiple individual work areas, typically separated by movable partitions and circulation areas. Individual work areas typically contain a computer, telephone, personal storage, and desk space for reading and writing. Furniture locations are not permanent and may change with needs and staffing. Open offices typically have one or more perimeter window walls which can provide views to the outdoors and usable daylight.

CONSIDERATIONS

Users' age, job function, and occupancy varies in each open office area. Work plane illuminance, as suggested by the IESNA, ranges from 30 fc to 50 fc for most office reading tasks. The visual needs of an older occupant in one work area may be different than that of a younger occupant. In most cases, the circulation space between work areas requires little if any lighting in addition to that provided for work areas. It is typical to find some work areas occupied and some vacant throughout the work day. Direct and reflected glare should be considered. Direct sunlight on work surfaces can contribute to glare and make it difficult to perform work. Lighting in the daylight zone (approximately twice the window head height) can often be turned off or reduced to a low power setting during the day.

RECOMMENDED LIGHTING POWER DENSITY AND ILLUMINANCE VALUES

Space Type	Target Illuminance	Target LPD
Common Spaces		
- Conference Room	40 fc	0.80 W/ft^2
- Corridor	10 fc	0.50 W/ft2
- Dining	20 fc	0.60 W/ft2
- Dishwashing/ Tray Return	50 fc	0.65 W/ft2
- Kitchen/ Food Prep/ Drive Thru	50 fc	0.65 W/ft2
- Living Quarters	5-30 fc	0.60 W/ft2
- Mechanical/ Electrical	30 fc	0.70 W/ft2
- Office (Open)	30-50 fc	0.70 W/ft2
- Office (Enclosed)	30-50 fc	0.80 W/ft2
- Reception/Waiting	15-30 fc	0.50 W/ft2
- Restroom/ Shower	20 fc	0.80 W/ft2
- Server Room	30 fc	0.85 W/ft2
- Serving Area	50 fc	0.70 W/ft2
- Stair	10 fc	0.50 W/ft2
- Storage (general)	10 fc	0.50 W/ft2
- Storage (dry food)	10 fc	0.70 W/ft2
- Telecom / Siprnet	50 fc	1.20 W/ft2
- Vault	40 fc	0.70 W/ft2
Training		
- Readiness Bay	40 fc	0.75 W/ft2
- Training Room (Small)	15-30 fc	0.70 W/ft2
Vehicle Maintenance		
- Consolidated Bench Repair	50 fc	0.60 W/ft2
- Repair Bay/ Vehicle Corridor	50 fc	0.85 W/ft2

Advanced HVAC Systems

When building heating, cooling, and electrical loads are significantly reduced, the importance of selecting one type of heating and cooling system over another diminishes.

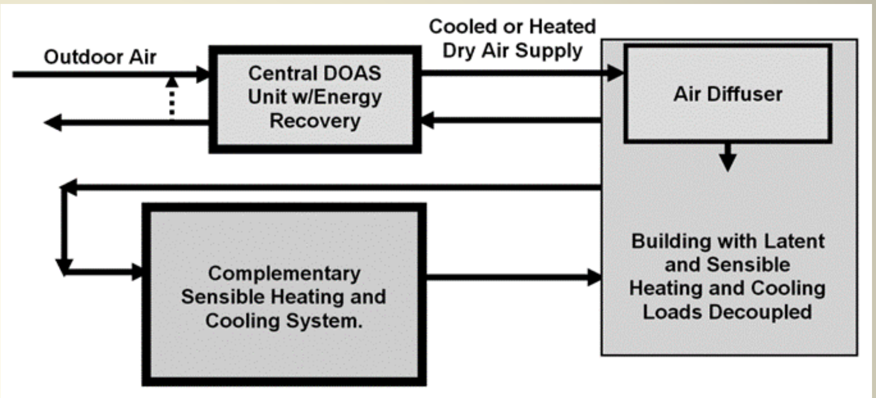
- Dedicated outdoor air system (DOAS)
- Heating and Cooling equipment per current national standard (e.g., ASHRAE 90.1-2013)
- Heat recovery (sensible and latent) > 80% efficiency
- Duct air tightness – Class C
- Hot and chilled water pipes insulation per current national standard

HVAC Systems

National standards for HVAC systems

Country	HVAC
Austria	EN 1507, EN 12237, ÖNORM H 5057, OIB RL 6, 2011
China	GB 50736-2012, GB 50189-2015
Denmark	Standard 447, Standard 452
Estonia	EVS-EN 13779, EN 12237, Ordinance No. 70. RT I, 09.11.2012, 12
Germany	EnEV 2014, DIN V 18599, DIN 1946- 6, DIN EN 13779 DIN 24192 II/III/IV, DIN 4108- 6, DIN 4701- 10
Latvia	Latvian Construction Standard LBN 231-03 Latvian Construction Standard LBN 003-01
UK	Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland: 2015 BS EN 15727:2010, BS 5422:2009
USA	ASHRAE Std 90.1 2013

Dedicated Outdoor Air System (DOAS) Schematic

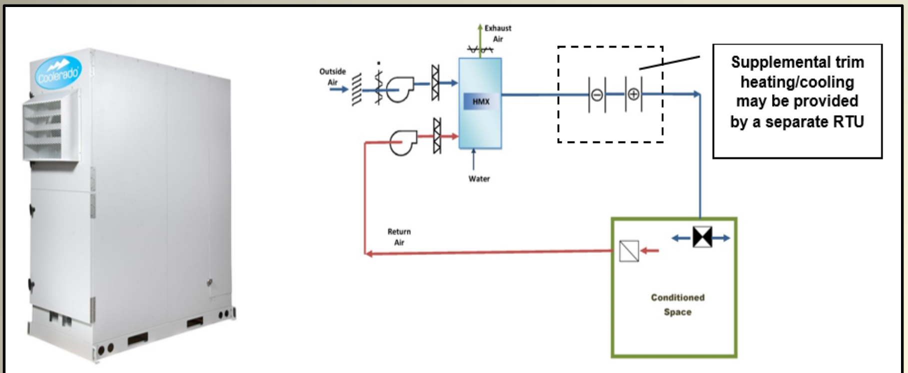


Minimum requirements to HR from return air

Country	Standard for HR equipment	Energy Type Recovered (total, sensible, latent)	Efficiency, %
Austria	ÖNORM EN 13141-7	Total	70
China	GB 50189-2015	Total and sensible	60
Denmark	Danish Building Regulations BR10 [48]	Sensible	70
Estonia	Ministry of Economic Affairs and Communications Ordinance No. 70. RT I, 09.11.2012, 12	Sensible	70
Germany	DIN 4108- 6, DIN 4701- 10, DIN EN 13053, EnEV 2014	Total	50% in average (depending on m³/h and h/a the range is 0.4- 0.65)
Latvia	Latvian Construction Standard LBN 231-15 of 16 June 2015.	Not defined	Not defined
UK	Non-Domestic Building Services Compliance Guide:2013 Non-Domestic Building Services Compliance Guide for Scotland: 2015	Sensible	Plate - 50 Heat pipe - 60 Heat wheel - 65 Runaround coil - 45
USA	ASHRAE Standard 90.1-2010	Total	> 50%

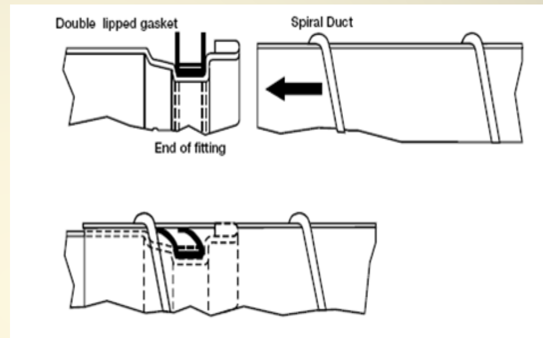
HVAC Systems

Hybrid DOAS using indirect evaporative cooling and heating with energy recovery ventilation



Duct airtightness classes

Airtightness class	Limiting leakage (l/s)/m² [cfm/ft²]
A –worst	< 1.32 (0.26)
B	< 0.44 (0.09)
C	< 0.15 (0.03)
D	< 0.05 (0.01)

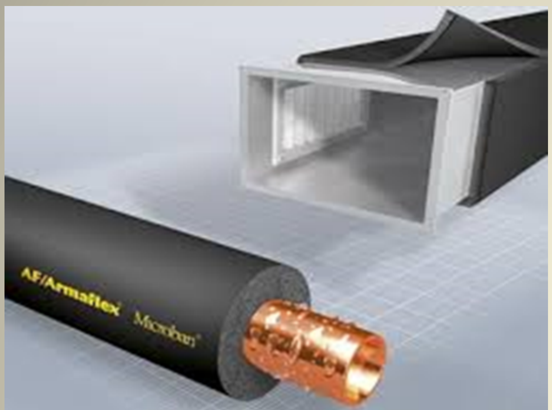


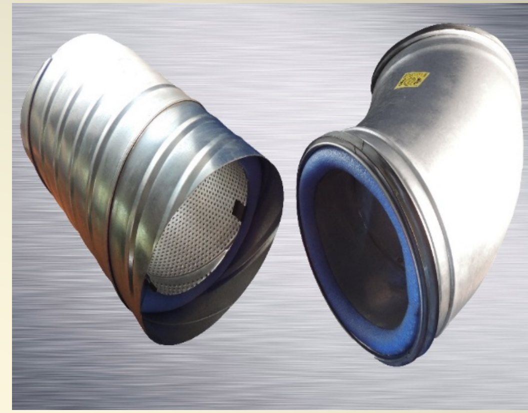
Mandatory duct leakage testing during construction and upon completion

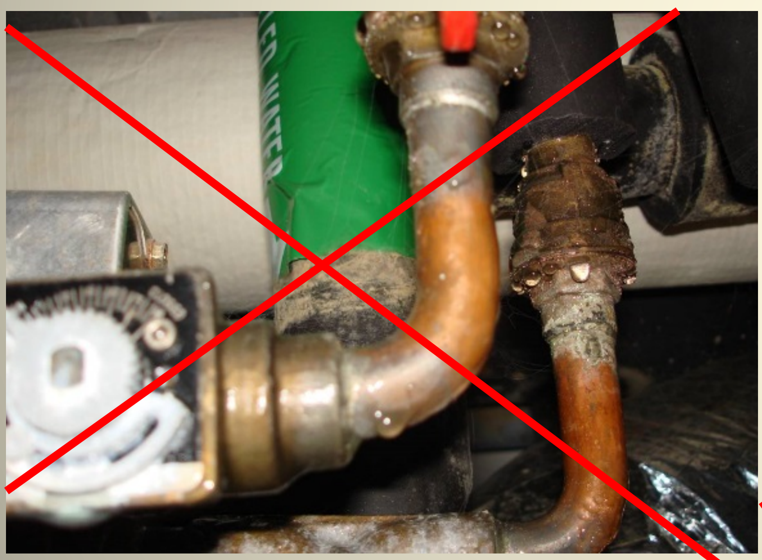
$$\Delta Q_{duct\ system\ section} \leq 0.003\ x\ \Delta p^{0.65}$$

Type of System	Minimum test pressure	Maximum allowable ductwork leakage, %
Small systems; split DX systems - usually under 2,000 cubic feet per minute (CFM) (940 l/s)	1.00 in. w.c. (250 pa)	2
Variable air volume (VAV) and constant air volume (CAV) boxes and associated downstream ductwork	1.00 in. w.c. (250 pa)	2
Single zone, multizone, low pressure VAV and CAV systems2, return ducts and exhaust duct systems	2.00 in. w.c. (500 pa)	2
All constant volume ducts in chases and concealed spaces, main return ducts on VAV and CAV systems, main ducts on exhaust or supply systems.	3.00 in. w.c. (745 pa)	1
Supply ducts for VAV and CAV systems	4.00 in. w.c.3 (995 pa)	1
High-pressure induction system	6.00 in. w.c.4 (1495 pa)	0.5

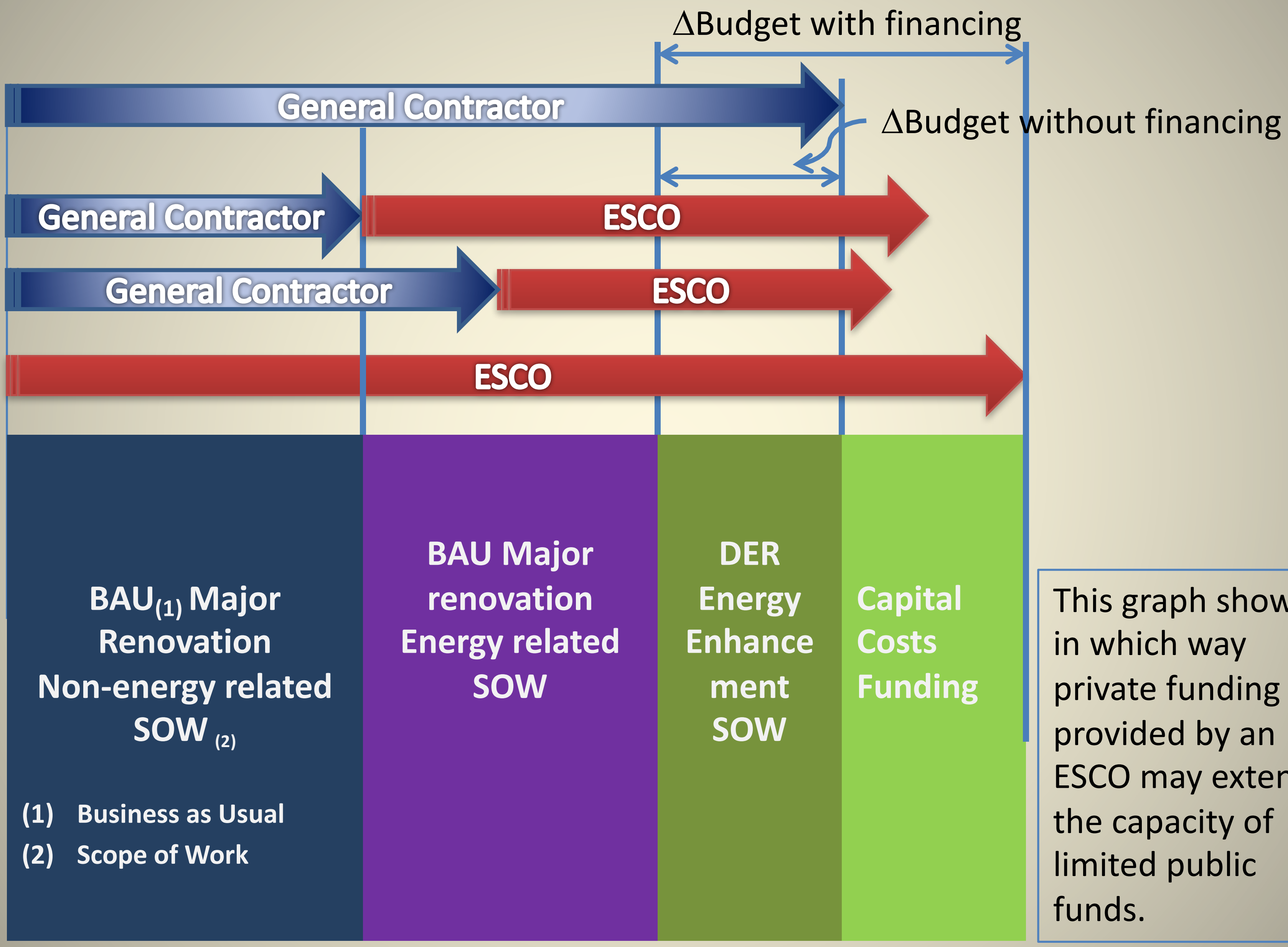
Ducts and Pipes Insulation







DER Implementation Strategies



This graph shows in which way private funding provided by an ESCO may extend the capacity of limited public funds.

Maximum (Cost Effective) Budget Increase for DER

$$\Delta \text{ Budget}_{max} = \text{NPV} [\Delta \text{ Energy (\$)}] + \text{NPV} [\Delta\text{Maintenance (\$)}] + \text{NPV} [\Delta\text{Replacement Cost (\$)}] + \text{NPV} [\Delta\text{Lease Revenues (\$)}]$$

$$\Delta \text{ Budget}_{max} = SR_E [\Delta \text{ Energy (\$)}] + S_M [\Delta\text{Maintenance}] + S_L [\Delta\text{Lease Revenues}]$$

$$\text{NPV} [\Delta G \times C_G] = [\Delta G]_{t=1} \times C_{G(t=1)} \times (1+e)/d-e) \times [1- (1+e)/1+d)]^N = [\Delta G]_{t=1} \times C_{G(t=1)} S_E$$

S_M and S_L scalars can be calculated and are the uniform present worth factor series that use the discount rate, the same way as SR_E with the escalation rate e=0%.

NPV = Net Present Value function

N = study life in years

d = discount rate

e = escalation rate

Conclusions

- To meet long term energy goals, **major renovation** of buildings must be **combined with DER**, targeting at least 50% of building site energy use reduction
- This reduction in energy use can be achieved by implementing a **limited number of core technologies bundled together**
- **These technologies are readily available and** will be **cost effective <u>as a bundle</u>** if DER is timed as a part of a major building renovation that already has allocated funds including those required to meet minimum energy requirements.
- **Characteristics of these technologies vary country by country**: e.g., thickness of insulation, mass produced thermally broken window frames, length of anchors, etc. **We need to create the DEMAND** by specifying high performing technologies that will result in **product availability and lower prices** in OUR MARKETPLACE": e.g., PV, triple-pane windows in Germany, airtight ductwork in Sweden, thick insulation in Denmark, high performance HR equipment in Scandinavia, LED, etc.
- Following the Army experience with building air tightness requirements, end users, architects, construction companies, and ESCOs need to be **trained in specifying, designing, and applying the limited number of core technologies required for DER.**
- **QA process starting with RFP development and contracting is essential** for DER and will minimize the cost of achieving energy and sustainability goals.