Communities and Local Government

Fabric Insulation – ways of further raising performance standards for all types of building fabric

BD 2428

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This report was finalised and delivered by the contractor to the Department in February 2005

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Department for Communities and Local Government

The findings in this report are those of the authors and do not necessarily represent those of the Department for Communities and Local Government.

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Contents

Executive Summary

1. This report summarises current building thermal performance requirements in Denmark, Germany, Switzerland and the Netherlands and classifies them according to the approach taken (elemental unit-based approach, target U-value average heat transmission through the building envelope, heat demand calculation or integrated energy use calculation). The regulations are compared to each other and contrasted with current and proposed UK building codes.

2. The regulations from three of the countries (Netherlands, Germany and Switzerland) are based on an energy use calculation method in combination with a maximum whole building transmission loss (Germany and the Netherlands) or maximum elemental U-values (Switzerland). In contrast, compliance with the regulations in Denmark is from a choice of elemental U-values, target U-value or a heat demand calculation, although the Danish regulations are expected to be changed in 2005 to an energy use methodology.

3. None of the countries express the energy performance target in terms of CO_2 emissions. The energy use targets for Germany and Switzerland are expressed in terms of primary energy (kWh or MJ) per m^2 usable floor area per annum. The Dutch energy target is expressed as a dimensionless measure (the EPC), which is the characteristic energy use of a building divided by the standardised primary energy use, and is designed to represent the energy use of an average size Dutch terraced house. The current Danish heat demand target is expressed as MJ per m^2 of usable floor area per annum. It is a measure of delivered energy only and does not take into account the efficiencies of heating or hot water installations. Other Danish regulations enforce the use of particular energy supply systems, such as the use of CHP and natural gas in preference to electricity where available.

4. The most stringent thermal requirements are those in the Swiss regulations. The Swiss code has an estimated maximum primary energy use of approximately 90 kWh/m^2/a for a typical domestic building (excluding lighting and domestic appliances), in combination with maximum elemental U-values of 0.3 W/m^2K for external walls, ground floor and roof, and 1.7 W/m^2K for windows, and preferred elemental U-value targets of 0.2 W/m^2K for external walls, ground floor and roof, and 1.2 W/m^2K for windows. Some Swiss cantons apply more demanding requirements than the federal regulations. For example, the Zurich canton has 20% lower energy targets and 30% lower U-value limits than the limits in the federal code[1].

[1] The primary to delivered energy ratio for electricity in Switzerland is 2.0 based on an energy mix of 60% hydroelectric and 40% nuclear. This is a quite different energy situation to the other three countries in this study, having a very low carbon factor.

5. Building form is considered as a factor in the Swiss, German and Dutch regulations. Building form is also considered in the Danish regulations, but the Danish energy target for domestic buildings does not include an area dependent term, with the expressed aim of promoting the design and construction of compact housing.

6. For all four countries, the primary aim of the thermal performance regulations is one of energy conservation, with the secondary considerations of thermal comfort and indoor air quality. The Swiss regulations form part of the 10 year 'Swiss Energy' plan, which has the stated objective of reductions in fossil fuel consumption and CO_2 emissions of 10% by 2010. The draft Danish 2005 regulations are intended to reduce energy consumption by 25-30% compared to new buildings built to the current code. The Dutch government has gradually tightened the target value of its energy performance coefficient (EPC) for domestic buildings from 1.4, when it was first introduced in 1996, to the current target of 1.0 (introduced in 2000), with the expressed aim of reducing energy consumption in buildings. The objective of the German EnEV regulations is a reduction in the energy requirements of new buildings by an average of 30% compared to the 1994 energy standards they replaced.

7. The classification of thermal performance targets for different types of building varies significantly between the four countries. In Switzerland, there are different energy targets for 12 categories of buildings. In Denmark, buildings are classified according to size (<1,500 m^2 and ≥1,500 m^2), with domestic and non-domestic sub-categories which dictate the thermal performance target. The Dutch regulations stipulate EPC targets according to two residential building types and 13 non-residential building types. The German classification is according to internal temperature (>19°C and ≤19°C), with different residential and non-residential performance targets for buildings heated to >19°C.

8. In the case of existing buildings in the Netherlands, the energy regulations apply to wholesale demolition and rebuilding of an existing building, for example, where existing foundations are reused or a building is refurbished after disassembly.
In Denmark, the requirements of the building regulations only apply to existing buildings when there is a substantial change in use or a substantial physical change to the building. In Germany, any extension of the heated space or newly installed appliances will have to comply with the regulations. Also in Germany, any major renovation (defined as a minimum of 20% of the surface of one side of a building wall, windows or roof) must meet the requirements of the thermal regulations and there are maximum U-values for replacement building components such as external walls and roofs (0.25 – 0.3 W/m^2K), windows (1.7 W/m^2K) and doors (2.9 W/m^2K). The far-reaching nature of these requirements reflects the relatively widespread use of external rendering and external insulation. The German authorities also require that boilers manufactured before October 1978 must be replaced by the end of 2006 and that all loft insulation will need to be upgraded to the new standards by

the end of 2006. The Swiss energy regulations apply specifically to major extensions to existing buildings. However, some cantons have rules that require compliance for major retrofitting of existing buildings and apply some form of cost-effectiveness analysis to determine whether renovation measures should take place.

9. In some of the countries (in particular, the Netherlands and Denmark), the direction of energy policy appears to be moving away from a position where there was a clear trend to introduce more stringent building energy regulations over time, towards a stance of more rigorous assessment of the cost-effectiveness and economic impact of proposed changes before introducing new energy codes.

10. The main emphasis of both policy and codes is towards new buildings, although it is recognised that more needs to be done to improve the energy performance of existing buildings.

11. There is relatively little monitoring of actual performance versus regulation in any of the countries studied.

12. Building energy reduction targets are linked to national energy and climate change policies and form an integral part of efforts to meet objectives under the Kyoto Protocol and EU burden sharing agreements.

13. The German, Swiss, Danish and Dutch regulatory authorities appear to be converging on an energy use calculation method which is compliant with EN 13790, with each of the countries adapting the standard to their own requirements, rather than referring to the standard directly.

Introduction

Classification of building thermal performance regulations

14. Thermal performance regulations for buildings can be classified according to four types (Beerepoot, 2002a). They can focus on a unit-based approach for the building elements (elemental approach), an average heat transmission through the building shell (target U-value), utilise a heat demand calculation or use a fully integrated energy use calculation. This report summarises current building energy codes for Denmark, Germany, Switzerland and the Netherlands and classifies them according to the approach taken.

15. This report expands on the interim report (Wingfield & Lowe, 2004), and where it was possible to obtain, incorporates comments and feedback from building regulation experts in the countries. The report establishes the context of building regulations in the target countries in areas such as:

    a) The extent of compliance with the letter of the regulation.
    b) The extent of physical checking of buildings.
    c) The relative proportions of applicants using specific compliance options where the regulations support more than one approach to compliance.
    d) The documentation supporting and underpinning regulations.
    e) The extent of the empirical basis for specific aspects of regulations.
    f) The extent and nature of mechanisms for establishing the impact of changes in regulation.
    g) Perceptions of the problems that have been thrown up by the existing regulations and of the shape of possible future developments in building regulation.
    h) The relationship of regulation to ongoing development of policies for sustainability and energy.

Description of thermal performance regulations by country

Denmark

Regulations for new buildings

16. The current Danish building energy regulations for new buildings were introduced in 1995 and 1998 (Boligministeriet, 1995 and 1998) and now include a heat demand calculation (referred to as 'Energy Frame' in Denmark). Prior to this, the regulations consisted of a set of maximum U-values and a transmission loss calculation with similarities to the Target U Value method. The new regulations had the effect of reducing nominal heating energy consumption by 25%. The 1998 regulations cover small buildings (<1,500 m^2) and the 1995 regulations apply to all other buildings. The current regulations do not currently cover heating/hot water installations, lighting or cooling. Compliance with the code can be by any of the three methods. The Energy Frame method is generally used only when the other two methods are not applicable (Svendson, 2004). The compliance criteria are summarised in Table 1.

17. The Danish heat demand (Energy Frame) calculation uses the following formula:

    $Q_H = Q_l - \eta(Q_S + Q_i)$ in kWh/month, where:

    Q_l = transmission and ventilation heat loss in kWh/month

    Q_S = solar heat gain in kWh/month

    Q_i = internal heat gain in kWh/month

    η = utilisation function

18. The Energy Frame requirement Q_{fr} is expressed in MJ/m^2 per year according to two different formulae, one for domestic buildings and one for non-domestic buildings. The formula for domestic buildings does not include any area dependent term, with the expressed aim of improving energy efficiency by promoting the design of compact buildings that minimise overall energy use, rather than energy use per m^2. The formula for domestic buildings is:

    $Q_{fr} = 160 + (140/e)$ in MJ/m^2 per year and may not exceed 280 MJ/m^2, where:

    e = number of storeys = heated floor area (m^2)/footprint of building (m^2)

Table 1 Summary of Danish building regulations compliance limits

Regulation Classification	Description of Method and Criteria	Compliance Values
Unit-based Approach	Maximum per Reports issued in 2008 mitted U-values for building components. Window and door area limited to 22% of the gross heated floor area. Rooms heated to not less than 18°C.	Maximum U-values (W/m²K) as follows: External walls <100 kg/m²: 0.20 External walls >100 kg/m²: 0.30 Basement floor to ground: 0.30 Walls to unheated spaces: 0.40 Floors/ceilings to unheated spaces: 0.30 Ground floors: 0.20 Ceilings and roof structures: 0.15 Flat roofs or sloping walls/roofs: 0.20 Windows, doors, skylights: 1.80
Transmission Loss Calculation	Thermal loss calculation used to demonstrate that different U-values from the maximum permitted result in the same heat loss.	Lowest acceptable U-values (W/m²K) as follows: External walls <100 kg/m²: 0.30 External walls >100 kg/m²: 0.40 Walls to unheated spaces: 0.60 Floors/ceilings to unheated spaces: 0.40 Ground floors, basement floors: 0.30 Industrial floors: 0.25 Ceilings and roof structures: 0.25 Flat roofs or sloping walls/roofs: 0.25 Windows, doors, skylights: 2.90
Heat Demand Calculation	Based on CEN 832. Monthly-based calculation. One average climatic zone giving the average weather conditions. Electric heating forbidden (except summerhouses). Includes effects of transmission heat loss, ventilation heat loss, internal heat gains, solar gains, unheated rooms, thermal capacity of materials. Airtightness is quoted as important but no limits are set. Does not take account of efficiencies of heating and hot water installations.	Same lowest acceptable U-values as per the transmission loss calculation method. Q_{fr} = maximum of 280 MJ/m² per year for both domestic and non-domestic buildings (equivalent to 78 kWh/m²/a). Where mechanical ventilation is used (over 0.5 ac/h for domestic and 2 ac/h for non-domestic), the maximum energy requirement is increased by the amount of energy needed to heat the air.

19. The Energy Frame formula for non-domestic buildings is as follows:

    $Q_{fr} = 110 + (5000/A_{byg}) + (110/e)$ in MJ/m^2 per year and may not exceed 280 MJ/m^2, where:

    A_{byg} = footprint of building (m^2)

    e = number of storeys = heated floor area (m^2)/footprint of building (m^2)

20. The regulations require that thermal bridges in building components, including external windows and doors, be minimised to avoid condensation. When calculating the U-values of individual components the effect of thermal bridges must be included in the calculation. Procedures for calculating heating energy consumption are documented in Danish Standard DS418 and calculation software in simple and expert versions is available from the Danish Building Research Institute.

21. Airtightness is quoted as important ("Buildings ... shall be so constructed that heat losses are not significantly increased as a result of ... unintended passage of air"), but no actual limits are set. The Energy Frame calculation procedure assumes a background air change rate of 0.5 h^{-1}. If specific requirements for mechanical exhaust in areas such as toilets, kitchens and bathrooms result in an overall air change rate greater than 0.5 h^{-1}, then the Energy Frame requirement is increased by q_r (MJ/m^2) according to the following equation to make it easier to fulfil the requirements of both ventilation and energy:

    $\Delta q_r = 400 * (q_{vm} - 0.3)$ where:

    q_{vm} = the exhausted volume flow rate in litres per second per m^2 of heated floor area

22. All ventilation systems with both air supply and exhaust must be equipped with some form of heat recovery such as a plate heat exchanger.

23. The only renewable energy that the Energy Frame method takes account of is passive solar gain.

24. Recent amendments (in 1998) to the regulations have added some limits for specific thermal bridges. For example, the maximum linear thermal transmittance of foundations is 0.25 W/mK and for junctions between windows and wall, such as sills and jambs, 0.03 W/mK.

25. In cases where underfloor heating is used, the requirements for the maximum U-value of the floor changes to 0.2 W/m^2K and the maximum linear thermal transmittance of foundations to 0.2 W/mK.

Regulations for existing buildings

26. The requirements of the building regulations apply only to existing buildings when there is a substantial change in use (such as conversion to flats) or a substantial physical change to the building such as an extension. Information from the ENPER report on existing buildings (ENPER, 2004) is that, in principle, measures such as improved heating and upgraded insulation should be carried out for major renovations/conversions, but in practice they are rarely done.

27. Under new 1997 energy labelling regulations, sellers of small buildings must have available to any prospective buyer an energy plan and energy rating that is less than three years old (this also therefore applies to new buildings when they first go on sale). The heating energy rating for small buildings is assessed by a consultant on a scale A, B or C (A being the highest) and further sub-divided from 1 to 5, 1 being the highest). A1 is therefore the best rating and C5 the worst. The rating takes account of: transmission loss; ventilation loss; hot water heating requirement; heat loss in pipework and efficiency of heat-producing plant. The heat demand is offset against any heat gain from solar radiation, internal heat gains and any supplement from any renewable energy source such as solar water heating. There is a separate electrical requirement equipment rating.

28. For larger buildings (domestic and non-domestic) the rating is based on actual annual consumption and includes energy use and CO_2 emissions. The plan contains proposals for energy/water savings measures and estimated benefits. The plan and rating must be updated annually (Van Velsen, 1998).

29. The expectation is that the energy rating regulations will stimulate building owners to improve the energy performance of their buildings owing to awareness, market pressure and better informed purchasers and users.

30. The Danish Heat Supply Act of 1994 prohibits the installation of electric heating in existing dwellings that are located in areas supplied with a district heating network or gas supply (Van Velsen, 1998).

31. The maximum U-value for any window that is replaced in a building is 1.8 W/m^2K.

Future regulations

32. The regulations for new buildings are due to change in 2005/2006 and are expected to be based on an energy performance calculation (MURE II Database). Demands will also be set for larger existing buildings.

Building control

33. Applications for building permits are submitted to the local authorities (Kommune) who conduct the necessary technical checks. When a permit is given, the local authority can stipulate that it be notified at different stages of building work, so that

it can inspect works if deemed necessary. The actual degree of site inspection by the authorities is variable. Occasionally, post-completion acoustic measurements may be required, but that is the limit of performance measurement. A permit for use is required for large buildings but is not necessary for dwellings which fall under the regulations for small buildings (Meijer, Visscher & Sheridan, 2002).

Germany

Regulations for new buildings

34. The current national building energy regulations in Germany were introduced on 1st February 2002 (Bundesministerium für Wirtschaft, 2001a). They are called the 'Energieeinsparverordnung' or 'EnEV' for short. There are also additional building regulations enacted by the 'Bundesländer' (states), which means that there can be some regional variation in the codes.

35. The EnEV regulations combine the transmission losses in buildings and their annual primary energy use into a single energy performance code, and the calculation is based on EN 13790. For the purposes of the code, building types are split into those that are heated above 19°C, such as dwellings, schools etc., and those with lower internal temperatures (12°C to 19°C), which are mainly industrial buildings.

36. The EnEV calculation method is based on seasonal calculations and a single zone building model. The main requirement is for annual primary energy usage, with a secondary requirement for transmission losses integrated into the energy performance calculation. The requirements are related to the ratio of the building's heat loss surface A (m^2) and volume V_e (m^3). The transmission losses are calculated by the U-values of the construction element surfaces. For a simplified version of the calculation, these U-values are multiplied by a correction factor (F_{xi}) according to the space adjoining the building element. Examples of correction factors are as follows:

Facade/window to outside	1
Roof to outside	1
Ceiling to loft space	0.8
Walls/floor to unheated space	0.5
Floor to unheated cellar	0.6

37. The first step in the calculation of the primary energy is to establish the building's energy demand using a heat demand calculation. The second step is to convert this to primary energy by multiplying by a conversion factor specific to the heating installation. The formula for annual primary energy Q_p (kWh/m^2a) is as follows:

$Q_p = (Q_h + Q_w) * e_p$ where:

Q_h = yearly space heat demand

Q_w = surcharge for hot water production

e_p = conversion factor for the heating installation

38. The limiting values for transmission losses and primary energy use are related to the ratio of the building's heat loss surface area to volume (A / V_e) and are summarised in Table 2. Estimated maximum energy consumption for typical house configurations would be 153 kWh/m^2/a for a detached house and 140 kWh/m^2/a for a terraced house (both include an estimate of 10 kWh/m^2/a for lighting) (PREDAC, 2003).

39. An energy certificate (Energiebedarfsausweis or Energiepass) is required to show compliance with the regulations (Bundesministerium für Wirtschaft, 2001b). The certificate has three parts as follows:

    a) General data on the building.

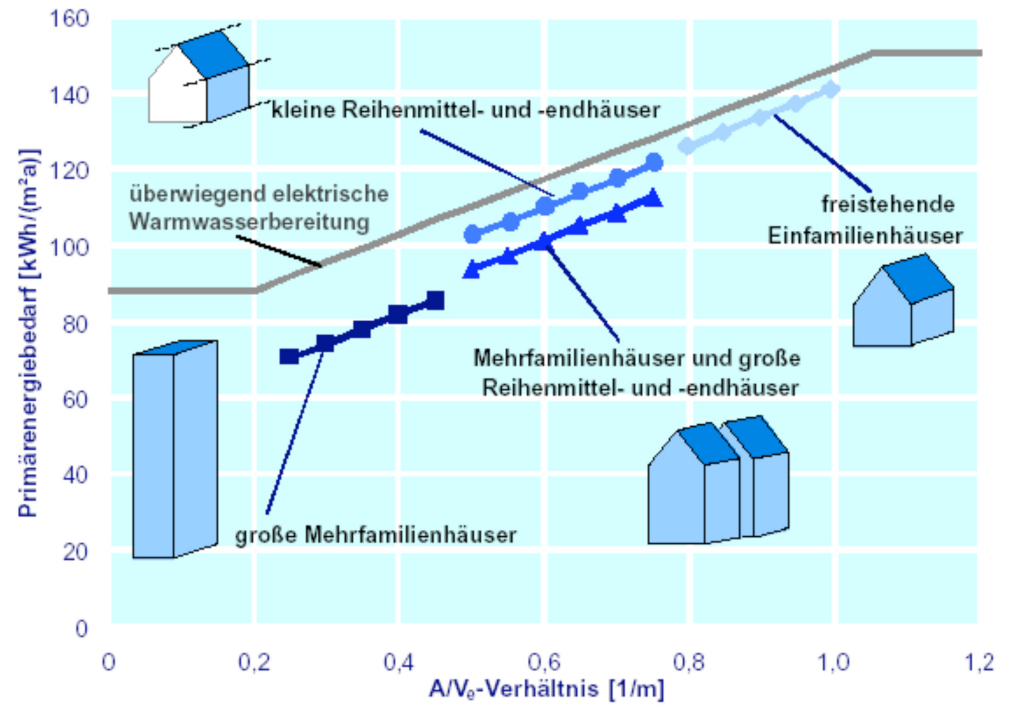
    b) Compliance on primary energy use requirements.

    c) Compliance on the transmission loss requirements and other factors such as airtightness, ventilation and summer comfort (applicable if a 30% facade glazing limit has been exceeded).

Table 2 Limiting thermal values under German EnEV regulations (after Beerepoot, 2002a)

A/V_e Ratio	Maximum Primary Energy Demand Q_p			Maximum Transmission Loss HT (W/m²K)	
	Residential Buildings (kWh/m²/a)	Residential Buildings with Electrical Hot Water (kWh/m²/a)	Other Buildings Q_p (by volume) (kWh/m³/a)	All Buildings with Window Proportion ≤ 30%	Non-residential Buildings with Window Proportion ≥ 30%
≤ 0.2	$66 + ((2600/(100+A_N))$	88.00	14.72	1.05	1.55
0.3	$50.94 + (70.29 * A/V_e) + 2600/(100 + A_N)$ (A_N = usable floor surface = $0.32 * V_e$)	95.53	17.13	0.80	1.15
0.4		103.06	19.54	0.68	0.95
0.5		110.58	21.95	0.60	0.83
0.6		118.11	24.36	0.55	0.75
0.7		125.64	26.77	0.51	0.69
0.8		133.17	29.18	0.49	0.65
0.9		140.70	31.59	0.47	0.62
1.0		148.23	34.00	0.45	0.59
≥ 1.05	$130 + 2600/(100 + A_N)$	152.00	35.21	0.44	0.58

Figure 1 Graph of primary energy demand versus A/V_e (Bundesministerium für Wirtschaft, 2001a)



40. Some other specific features of the regulations include:

a) Mandatory shading requirement for buildings with glazed area greater than 30% of the facade.

b) Regulations based on one average climatic zone.

c) The energy aspects included in the calculation are those for heating, domestic hot water and ventilation.

d) In terms of airtightness, the building must be designed with 'state of the art' features for controlling air infiltration and the joints of windows and doors must meet the requirements of the relevant DIN standard for air leakage of components (DIN EN 12207). There is an option to conduct an airtightness test. If the test result is better (ac/h at 50Pa) than 3 h^{-1} for naturally ventilated buildings, and 1.5 h^{-1} for buildings with a mechanical ventilation system, then a 15% reduction in the air infiltration loss is allowed in the energy calculation.

e) Thermal bridges should be minimised and need to be considered as part of the annual heat demand calculation. This can be done in one of three ways. A full calculation of all thermal junctions and bridges using numerical modelling (according to DIN 4108), a transmission loss U-value penalty of 0.1 W/m^{2}K (added to each element) for all the external envelope elements or a transmission loss U-value penalty of 0.05 W/m^{2}K (added to each element) for all the external elements if the building design uses robust details outlined in DIN 4108.

Regulations for existing buildings

41. Generally, EnEV applies to new buildings. However, there are certain requirements for existing buildings. Any extension of the heated space (if volume is greater than 30 m^3) or newly installed appliances will have to comply fully with the regulations. Any major renovation (defined as a minimum of 20% of the surface of one side of a building wall, windows or roof) must meet the requirements of the new regulations. The regulations do not apply merely as a result of a change of use. There are maximum U-values for renovations of building components or construction elements such as facades, windows, doors and roofs. The conditions when compliance is required can vary from "when replaced" to, for example, "when outside render is replaced". Examples of limiting values for components for buildings with inside temperature >19°C include:

Outside door	Max U-value 2.9 W/m^{2}K
Facade	U-value range 0.35 – 0.45 W/m^{2}K
Windows(including frame)	Max U-value 1.7 W/m^{2}K
Glazing (centre pane)	Max U-value 1.5 W/m^{2}K
Roofs/floors	U-value range 0.25 – 0.30 W/m^{2}K
Roofs/floors adjoining unheated space	U-value range 0.40 – 0.50 W/m^{2}K

42. A range of mandatory energy improvements are also in place. All boilers manufactured before October 1978 must be replaced by the end of 2006. Accessible, non-insulated pipework must be insulated by the end of 2006. Insulation in accessible lofts will also need to be upgraded by the end of 2006. In some of the Länder, enforcement of the regulations for boiler and pipework upgrades will be controlled by authorised chimney-sweeps. The authorised chimney-sweeps conduct an annual inspection on all boilers and heating systems between 4 and 400 kW, irrespective of building type (ENPER, 2003).

43. The problem of the expected short lifetime of heating and hot water installations (around 15 years) when compared with the much longer lifetime of the building fabric (60+ years) is tackled within the EnEV codes. The regulations require that, when any change is made to a building's insulation or heating system, then the new installation must feature the same level of energy efficiency (or better) than the old components.

Building control

44. In Germany, local building control authorities are responsible for building permits and building control. In addition, officially recognised engineers (Prüfingenieure) are authorised to conduct some aspects of public building control such as technical checks and outside inspection. When the plans are submitted to the local authority, they must be accompanied with proof of compliance with the thermal, acoustic and structural requirements. These must be submitted by an architect or engineer with at least two years' experience as a building control engineer. The main standard inspection is conducted when the structural framing is complete. The building components necessary for fire safety, and thermal and sound insulation must be left exposed for checking. Work on the interior of the building cannot commence until the structural frame notice is issued. For dwellings with no habitable space more than 10 m above ground level, there is a simplified approval procedure (Meijer et al, 2002).

The Netherlands

Regulations for new buildings

45. The latest Dutch technical building regulations (Building Decree or 'Bouwbesluit') were introduced in 2003 (Novem, 2003). Since 1996, the energy performance characteristics of buildings have been expressed using the 'Energy Performance Coefficient' or EPC, and this is still a feature of the new regulations. The EPC is a dimensionless measure that includes all the energy features of a building and their efficiency. The EPC is bounded by a maximum figure that is set in the building regulations. The method for calculating the EPC for domestic buildings is given in the Dutch standard NEN 5128 (NIN, 2001a) and for non-domestic buildings in standard NEN 2916 (NIN, 2001b), and is based on EN 832/EN 13790. Non-residential buildings are sub-classified into 13 different categories (eg schools, hospitals, industrial

buildings) and residential buildings into two categories (dwellings/apartments and recreational accommodation such as holiday cottages/mobile homes). The maximum allowable EPC value varies according to the category.

46. There are no alternatives to the EPC calculation and no simplified method.

47. The reasons given by the Dutch authorities for using an energy performance type of calculation (Beerepoot, 2002a) are that:

    a) It allows architects/developers more freedom when designing to comply with the regulations by allowing them to choose the combination of energy efficiency measures that best suits the requirements of the building design.
    b) It covers more aspects of energy use than insulation effectiveness.

48. The regulations allow local authorities to demand a lower EPC if they wish.

49. The EPC calculation takes into account building geometry and the energy consumption for heating, hot water, ventilation, lighting, pumps, fans and humidification.

50. The EPC is defined as the "characteristic energy use of a building divided by the standardised energy use". The basic formula for the EPC calculation is as follows:

    $EPC = Q_{pres:tot}/((330 * A_{g:verwz}) + (65 * A_{verlies}))$ where:

    $Q_{pres:tot}$ = the characteristic (primary) energy use of the building (MJ)

    $A_{g:verwz}$ = the floor area (defined as the floor surface area of heated zones where the ceiling height is ≥1 .5 m minus the floor surface area of stair, technical spaces and ducts)

    $A_{verlies}$ = the loss surface (the external surface area of construction elements facing the outside and ground)

51. The constants in the EPC equation were chosen to make the EPC value equate to a primary energy demand in m^3 of natural gas equivalent for a reference Dutch dwelling of the type "of the size and shape built most often". An EPC value of 1.4 is equivalent to 1,400 m^3 natural gas (54.6 GJ), 1.0 is equivalent to 1,000 m^3 natural gas (39 GJ) (Dougle, 1999). The typical dwelling is a single family terraced house with four occupants and a floor area of 80 m^2.

52. Maximum allowed EPC values for some of the different building types are illustrated in Table 3. Since it was first introduced in 1996, the maximum allowable value for the EPC has gradually been reduced with building regulation changes. In 1996 the target for dwellings was initially set at 1.4. In the 1998 regulation change this was reduced to 1.2. The current value for dwellings in the 2003 regulations has been set at 1.0.

Indications are that the Dutch authorities do not intend to reduce the target value further for the foreseeable future.

Table 3 Examples of EPC maximum values

Building Type	EPC limit
Dwelling	1.0
Office	1.5
Sports Facility	1.8
Shopping Centre	3.4

53. Estimated maximum energy consumption for typical house configurations would be 117 kWh/m^2/a for a detached house and 104 kWh/m^2/a for a terraced house (PREDAC, 2003 – values adjusted for change in EPC limit from 1.2 to 1.0).

54. The EPC includes calculations of transmission loss and heat demand and is based to a great extent on EN832. Although there has been some harmonisation in the two EPC calculation standards, there is a difference in the actual methodology used for domestic and non-domestic buildings. In the case of domestic buildings, the method is a quasi-static energy calculation based on heating seasons. For non-domestic buildings, the method is based on monthly calculations.

55. In the case of lighting, energy use is based on agreed typical energy consumption per m^2 that is currently set at a generous 56.4 MJ/m^2 (16 kWh/m^2). This is to take account of the influence of differences in lighting usage patterns and that occupants can and will add or remove lighting capacity.

56. Some other specific features of the Dutch regulations are as follows:

   a) The heat loss due to the length of the heating system pipework to the point of supply is taken into account.

   b) Full compliance with the regulations using electrical heating systems is extremely difficult due to the fact that output performance is linked to the inefficient conversion factor from primary energy.

   c) Air leakage through the building envelope should not exceed 0.2 m^3/s at 10Pa (per 500 m^3 of building volume) according to Dutch standard NEN2686 (equivalent to an air change rate of around 5 h^{-1} at 50Pa (Limb, 2001)). Airtightness can have a significant impact on the results of the calculation but there is no provision in the Netherlands for monitoring airtightness after construction.

   d) Ventilation systems are taken into account in terms of their energy usage (fans etc) and energy conservation in terms of ventilation heat recovery.

e) Thermal mass is not considered in the calculation.

f) Energy produced by photovoltaic systems is taken into account by offsetting the electricity produced against any electrical energy used for lighting, heating and ventilation. Solar hot water systems are also considered in the calculation.

g) The U-values of doors, windows and their frames may not exceed 4.2 W/m^2K. In practice, this would mean double-glazed windows would normally be required.

h) The thermal insulation of the building shell should be such that the average thermal resistance of the external envelope of a dwelling will be a minimum of 2.5 m^2K/W. This would be equivalent to an overall target U-value of 0.4 W/m^2K. In practice, this limit is unlikely to be reached due to the high levels of insulation that would be required to meet the energy performance targets.

i) Up to 2% of the total surface area of the dwelling is exempt from the minimum prescribed insulation level.

Regulations for existing buildings

57. The energy regulations apply in the case of wholesale demolition and rebuilding of an existing building, for example, where existing foundations are reused or a building is refurbished after disassembly (Beerepoot, 2002b). Local authorities have the power to reduce the energy performance requirement for replacement buildings on economic grounds (ENPER, 2004).

58. When a building permit is deemed to be needed for the replacement of fittings (for example, this can be the case with the replacement of windows, doors and rooflights on a major scale), the building needs to meet the EP standard for new buildings (ENPER, 2004). It is possible for the municipal authorities to lower the demands to a minimum level of the energy performance which the building had when it was built, or to somewhere in between this minimum level and the level for new buildings.

59. The building decree lays down some minimum quality levels for the state of existing buildings. However, this does not include any that refer to the thermal performance of existing buildings.

60. The EPA scheme (Energy Performance Advice) is an energy audit carried out by certified advisors. It can be requested by owners, landlords or tenants of buildings to identify opportunities to improve the energy efficiency of a building. If the identified measures are actually implemented, then the consultation is free, and there will be subsidies available for some of the costs of implementation. The EPA scheme was designed to be compatible with the requirements for energy labelling under the European Energy Performance Directive, but is considered by some as too complex (Jeeninga, 2004).

61. A building must always maintain the level of energy performance that it had when it was built. This means that when, for instance, a heating or ventilation system needs to be changed, it should be replaced with a system which is at least as energy efficient as the old one. If a less energy efficient installation is used, the energy use has to be compensated in such a way (eg by improved insulation) that the overall energy performance meets the original design (ENPER, 2004).

62. The Environmental Protection Law says that buildings with a high electricity, gas or water use (usually industrial buildings) must investigate energy and water saving measures and should apply cost benefit analysis to potential improvement measures (usually payback times should be less than five years). In practice there are no sanctions, so enforcement of this law is difficult (ENPER, 2004).

Future regulations

63. The Dutch authorities are also developing an energy performance calculation method for a complete building site/development. Known as 'EPL', this method aims to address issues of energy conservation that are applicable to whole building developments. These might include site design, renewable energy production, CHP and district heating, as well as the performance of the buildings themselves. Output of the calculation is in terms of CO_2 emissions. Policy indications are that there is a move to make integrated whole site performance more important than individual building performance and, indeed, may even replace it (Beerepoot, 2002b).

64. The Dutch authorities have stated that modifications to the building regulations will not take place more than once per year, and that any changes will be notified well in advance (VROM, 2001a).

Building control

65. Building permits in the Netherlands are issued by municipal council building control, who will check the technical compliance of any application. Inspections are usually carried out at strategic points in the construction, although there are no regulations concerning the frequency or rigour of inspection. There are no completion certificates (Meijer et al, 2002). The Dutch authorities have stated that there are failings in the enforcement of the building regulations, and that consequently the municipal authorities will be required to improve their performance and that there will be an increase in the supervisory role of the Housing Inspectorate (VROM, 2001a).

Switzerland

Regulations for new buildings

66. The Swiss Federal Office of Energy (SFOE) carries out the development and implementation of federal energy policy in Switzerland. 'SwissEnergy' is the federal programme developed to achieve energy and climate policy objectives. This involves co-operation between the two main levels of government – federal and cantonal. The new federal Energy Law shifts the burden of responsibility onto the cantons, particularly in the case of building energy requirements. The most important duties of the cantons under the SwissEnergy programme related to buildings are as follows:

a) Building-related legislation to be brought into line with the 'state of the art' and ensure its proper implementation. In particular, the new building energy standard SIA 380/1 (SIA, 2001), at a minimum, is expected to be incorporated into cantonal legislation.

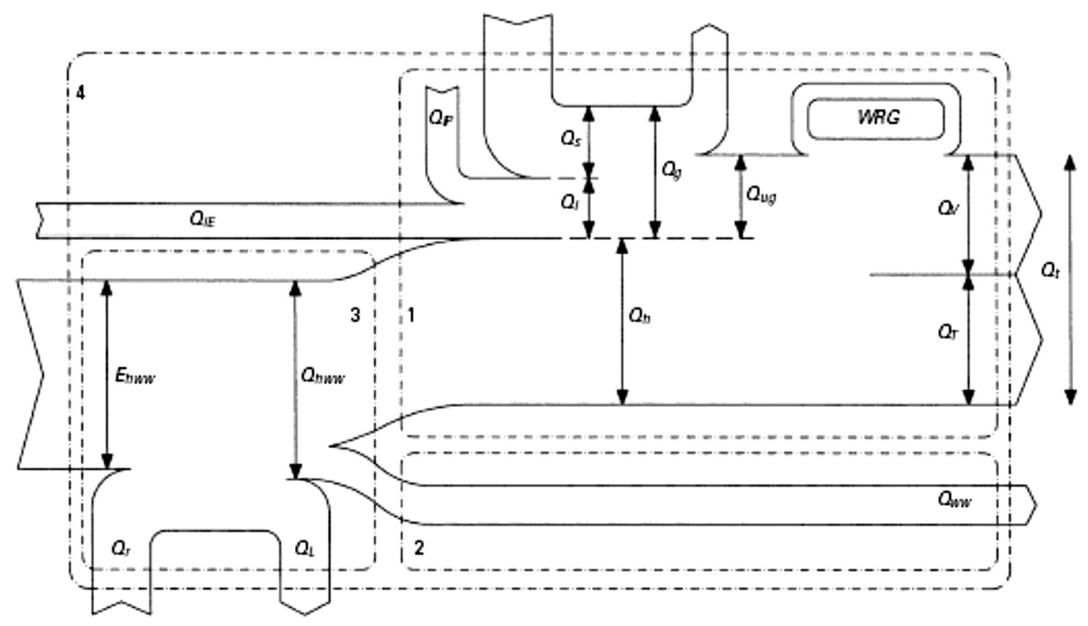
b) Ensure that the energy regulations are actually applied in buildings by conducting spot checks on buildings. The federal authorities will give the cantons all necessary support in preparing suitable instruments for implementation and control.

c) The cantons are expected to lead by example, in particular, through demonstration programmes on their own buildings. Priority is also placed on the promotion of the demonstration projects and on professional education and training. Many cantons already support the voluntary Minergie energy standard (Swiss equivalent of the Passive House standard) for their own buildings, which has more stringent energy targets than the federal minimum and is also applied to existing buildings as well as new buildings.

67. The Swiss SIA 380/1 standard is a full energy use calculation method based on EN 13790. It considers the full energy balance of the building as illustrated in Figure 2 (where: E_{hww} = delivered energy requirement for heating and warm water, Q_g = heat gains, Q_h = heating heat requirement, Q_{hww} = useful heat for heating and warm water, Q_i = internal heat gains, Q_{iE} = internal electrical heat gains, Q_{iP} = internal heat gains people, Q_L = heat losses heating and warm water, Q_r = heat gains heating and warm water, Q_A = solar heat gains, Q_T = transmission heat loss, Q_t = total heat loss, Q_{ug} = used heat gains, Q_V = ventilation heat loss, Q_{ww} = heat requirement for warm water, WRG = heat recovery).[2]

[2] Cooling requirements are covered in SIA 382/2.

Figure 2 Building energy balance diagram (after SIA, 2001)



68. Twelve different categories of building are defined in the regulations, as shown in Table 4. The target energy requirement varies according to the building type.

69. For each of the building categories there are assumed values for electrical energy consumption, internal temperature, air leakage and other factors, for use in the energy use calculation. These are summarised in Table 5.

Table 4 Swiss code building categories

Building Category Number	Building Category	Category Examples
I	Dwelling – MFM	Multi-Family House, Hotel, Flats
II	Dwelling – EFH	Single Family House, Two Family House, Terraced House
III	Administrative Building	Office, Library, Surgery
IV	School	School, Nursery, Research Institute
V	Retail	Shop, Shopping Centre
VI	Restaurants	Restaurant, Bar, Club
VII	Meeting Places	Church, Cinema, Theatre, Concert Hall
VIII	Medical	Hospital, Treatment Clinic, Care Home
IX	Industrial	Factory, Railway Station, Fire Station, Workshop
X	Storage	Distribution Centre, Storage Building
XI	Sports	Stadium, Fitness Centre, Sports Hall
XII	Swimming Pool	Swimming Pool, Therapeutic Bath, Sauna Building

Table 5 Assumed factors and limiting usage values for different building types

Building Category (See Table 4)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Internal Temperature Target (°C)	20	20	20	20	20	20	20	22	18	18	18	28
Occupation Density (m^2/person)	40	60	20	10	10	5	5	30	20	100	20	20
Person Heat Gain (W/person)	70	70	80	70	90	100	80	80	100	100	100	60
Occupation Time (h/day)	12	12	6	4	4	3	3	16	6	6	6	4
Annual Electricity Consumption (MJ/m^2)	100	80	80	40	120	120	60	100	60	20	20	200
Electricity Consumption Correction Factor	0.7	0.7	0.9	0.9	0.8	0.7	0.8	0.7	0.9	0.9	0.9	0.7
Air Leakage (m^3/h/m^2) at 4Pa	0.7	0.7	0.7	0.7	0.7	1.2	1.0	1.0	0.7	0.3	0.7	0.7
Approximate Air Leakage Normalised to ac/h at 50Pa (h^{-1}) (after Limb, 2001)	3	3	3	3	3	5.2	4.2	4.2	3	1.3	3	3
Hot Water Heating Requirement (MJ/m^2)	75	50	25	25	25	200	50	100	25	5	300	300

70. The maximum targets for heating consumption (MJ/m^2) for the various types of new buildings are derived from the following equation:

$H_g = H_{g0} + (\Delta H_g * (A/EBF))$ where:

A = Building external envelope area (m^2)

EBF = Energy related floor surface area (corrected for room height) (m^2)

(A/EBF is therefore a dimensionless value that is characteristic of the building shape)

$H_{g0} + \Delta H_g$ are the target values given in Table 6.

Table 6. Limiting values for building heating energy consumption of new buildings		
Building Category	**Limiting Values**	
	H_{g0} (MJ/m²)	**ΔH_g (MJ/m²)**
I Dwelling – MFM	80	90
II Dwelling – EFH	90	90
III Administrative Building	75	90
IV School	90	90
V Retail	60	90
VI Restaurants	95	90
VII Meeting Places	105	90
VIII Medical	100	100
IX Industrial	75	80
X Storage	80	80
XI Sports	95	80
XII Swimming Pool	70	130

71. The targets for heating energy consumption are based on an average annual temperature of 8.5°C and are adjusted by 4% per °C higher or lower, depending upon typical local climatic conditions. The targets are also adjusted according to height above sea level (norm is at 500 m with adjustments of ± 3% per 100 m). As well as setting maximum values as in Table 6, the regulations also have stated preferred target values. These are set at 60% of the maximum limits.

72. Minimum expected efficiencies are set out in the regulations for different types of energy source such as gas, oil, electric, heat pump etc.

73. As well as meeting the energy calculation requirements, the standard also sets maximum values for U-values for the external envelopes of zones in buildings (Figure 3) and for components (Table 7).

Figure 3 U-value limits for different building zones (beheizt = heated) (after SIA, 2001)

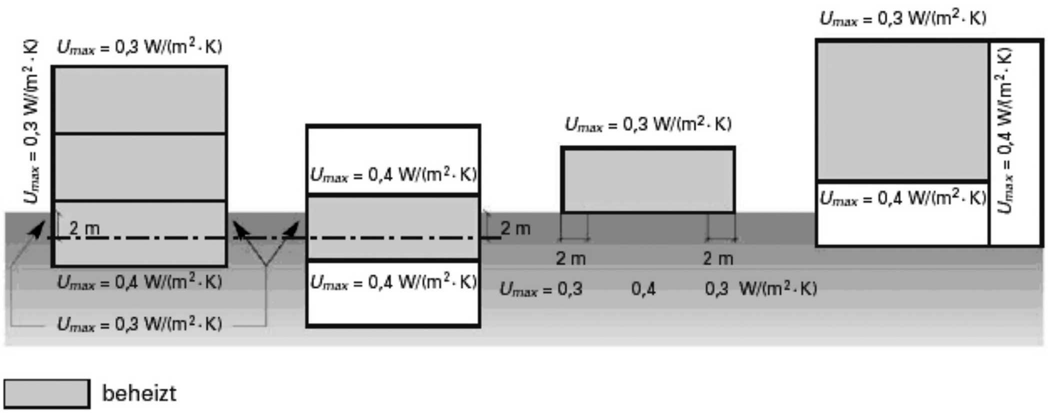


Table 7 Example U-value limits for building components (applies to regions with average annual temperature between 7°C and 10°C, outside of this range adjust by ± 2% per K)

	Maximum U-value (W/m²K)		**Target U-value (W/m²K)**	
	Adjacent to Outside	**Adjacent to Unheated Space**	**Adjacent to Outside**	**Adjacent to Unheated Space**
Opaque Component (Wall, Floor, Roof)	0.3	0.4	0.2	0.3
Window, Glazed Door	1.7	2.0	1.2	1.6
Unglazed Door	2.0	2.0	1.6	2.0

74. Linear and point thermal bridges must be fully considered in the energy calculation. These can be modelled by simplified methods for commonly occurring thermal bridges, or by full computer modelling for more complex situations. There are limits for some specific common thermal bridges, as illustrated in Table 8.

Table 8 Thermal bridge limits

Thermal Bridge	**Limiting Value**
Cantilever Balcony Plate or Roof Slab (ψ)	0.3 W/mK
Interruption of Insulation Layer by Walls or Floors (ψ)	0.2 W/mK
Horizontal or Vertical Building Edge (ψ)	0.2 W/mK
Additional Window Framing (ψ)	0.3 W/mK
Window Lintel or Sill (ψ)	0.1 W/mK
Punctures or Penetrations of Insulation Layer (eg support, tie) (χ)	0.3 W/mK

75. Some example maximum energy values are illustrated in Table 9 for various building types with specific shape factors and different heating/hot water energy sources. These values are for buildings situated in central Switzerland and use the minimum allowable efficiency for the energy type.

Table 9 Example limiting energy values for buildings in central Switzerland (after SIA, 2001)

Building Category	A/EBF	Q_h (MJ/m²)	Q_{ww} (MJ/m²)	Heating Type	E_h (MJ/m²)	E_{WW} (MJ/m²)	E_{hww} (MJ/m²)
I Dwelling – MFM	1.3	197	75	Oil/Gas Combination Boiler	–	–	358
				Oil/Gas Heating & Gas Hot Water	232	125	357
				Oil/Gas Heating & Heat Pump Hot Water	232	38	270
II Dwelling – EFH	2.0	270	50	Oil/Gas Combination Boiler	–	–	401
				Oil/Gas Heating & Heat Pump Hot Water	318	25	343
				Electrical Heating and Hot Water	290	71	361
III Office	0.8	147	25	Oil/Gas Combination Boiler	–	–	215
				Oil/Gas Heating & Gas Hot Water	173	42	215
				District Heating with Combined Hot Water	–	–	198

76. As mentioned previously, the cantons are free to impose stricter limiting values if they wish. For example, the canton of Zurich has 20% lower energy targets and 30% lower U-value limits than SIA 380/1.

77. Some other specific features of the Swiss regulations are as follows:

a) The energy calculation is on a monthly basis using 22 different climatic zones. The climate data are available on the internet.

b) The energy targets for changes to a building are 140% of those for a new building.

c) Compulsory heat recovery for medium to large ventilation systems.

d) No heating allowed for uninsulated rooms or outdoor pools.

Regulations for existing buildings

78. The Swiss energy regulations apply specifically to new buildings and major extensions to existing buildings. However, some cantons have voluntary or compulsory regulations that require the application of SIA 380/1 for major retrofitting of existing buildings and also apply some form of cost-effectiveness analysis (LCA) to determine when renovation measures should be carried out (Santamouris, 2003).

79. Many cantons have adopted the 'Minergie' energy labelling code, especially for municipal buildings. The primary energy consumption of a new detached or terraced 'Minergie' standard house is 55 $kWh/m^2/a$ including lighting (PREDAC, 2003). According to the 'Minergie' website (Minergie, 2003), the requirement for both types of dwelling (multi-family and single-family) is 42 $kWh/m^2/a$ for a new building and 80 $kWh/m^2/a$ for an existing building built before 1990. Maximum U-values are stated as 0.20 W/m^2K for walls/floor/roof, 1.3 W/m^2K for windows and 1.6 W/m^2K for doors. The other building types also have limits. For example, offices, schools and shops have a threshold of 40 $kWh/m^2/a$ for a new building and 70 $kWh/m^2/a$ for an existing building built before 1990.

Future regulations

80. The 'SwissEnergy' programme is intended to last for 10 years until 2010. There are proposals, for example, to promote renewable energies by requiring that 20% of building heating energy requirement be met by renewables, with the option of offsetting this requirement with improved building envelope thermal efficiency.

Discussion

Primary objectives of the current regulations

81. In all four cases the primary aim of the thermal requirements of the building regulations appears to be energy conservation.

82. In the case of Switzerland, the new codes form part of the measures implemented under the 'SwissEnergy' programme (UVEK, 2001), which has the objective to reduce fossil fuel consumption and CO_2 emissions by 10% in 2010 compared to those in 2000. The Swiss government has tried to introduce levies on non-renewable fuel as part of the new Energy Law, but an early introduction of these was defeated in the federal parliament. It is now expected that the levies will eventually be introduced at the end of 2004.

83. The thermal requirements in the Danish regulations of 1995 and 1998 had the stated objective of reducing energy consumption by 25% when compared to the previous 1982 regulations. The regulations state that buildings should perform in such a way as to "avoid unnecessary fuel and power consumption and achieve a healthy indoor climate".

84. In the Netherlands, the building energy code is one of five areas covered by the building regulations. The Dutch government has gradually tightened the target value of the energy performance coefficient (EPC) since it was first introduced in 1996, with the expressed aim of reducing energy consumption in buildings. Some parts of the regulations cover occupant comfort issues, such as minimum ventilation rates and daylighting.

85. The main aim of the German EnEV regulations is that of energy conservation, with a target to reduce energy requirements of new buildings by an average of 30% compared to the standards it replaced (the Thermal Insulation Ordinance of 1994 and Heating Installation Ordinance of 1994) and 70% compared to existing stock. Some aspects of the new code do address issues of health. For example, there are requirements for airtightness, ventilation and summer comfort if more than 30% of the facade is glazed.

Future trajectory of regulations

86. The Dutch government discussed in 2001 reducing further the EPC target for residential buildings from its current limit of 1.0. However, after studying the potential economic impact of such a change it decided against any further tightening

of the standard at this moment in time. Also of concern were the effects of further reductions on indoor air quality, based on research that showed energy efficient houses have poor indoor air quality. However, it is expected that a reduction to 0.8 will be made in 2005 or 2006 (Jeeninga, 2004). Indications are that the Netherlands may be moving towards introducing regulations for whole developments (EPL) rather than any further changes on those for individual buildings. The regulations are likely to be compliant with the European Directive on the Energy Performance of Buildings (EPBD), with the requirement for energy labelling being met by the EPA scheme, although the scope of the EPA is much wider and more complicated than required by the directive (Jeeninga, 2004).

87. New outline regulations are in place in Denmark, which have been drafted in accordance with the Danish Energy Authority Energy Conservation Plan of May 2003. The regulations are intended to reduce energy consumption by 25-30% compared to new buildings built to the current regulations (BR-95 and BRS-98). The new regulations will also be designed to be compliant with the European Directive on the Energy Performance of Buildings and are expected to be in place in late 2004 or early 2005. The energy performance calculation method will be based on EN 13790. It is not known yet what the targets will be set at, but it is likely that the regulations will contain guidance U-values as well as an energy performance target (Bugge Garn, 2004). The expectation is that, in the future, there will be a further strengthening of the energy performance requirement of around 30% in 2010, and further 30% reductions in both 2015 and 2020. This would lead to an energy consumption for heating and cooling of around 15 kWh/m^2/a in 2020, equivalent to the current Passivhaus standard.

88. The current 'SwissEnergy' policy in Switzerland lasts until 2010 (UVEK, 2001).

89. There is no information available on future changes to the regulations in Germany. Some minor changes may be required to make the regulations conform to the European Directive.

Link between national energy policies and building regulation

Netherlands

90. Dutch energy policy is described in the latest governmental energy White Paper published in 1999 (VROM, 1999). The objective of the policy with regard to buildings is directed towards both residential and non-residential sectors. The White Paper also recognised that previous policy focused on new buildings, for example, by means of the EPN and EPL, and that future policy must also address emissions from existing building stock and cost-effective opportunities for saving energy in existing

houses identified. A target set for CO_2 reduction for dwellings built before 1995 was 2Mtonne by 2010 compared to the 1995 level. In order to achieve this reduction, the White Paper introduced the Energy Performance Advice (EPA) energy labelling system, stating that it would be voluntary to begin with. The maximum cost of energy improvement measures under the EPA was set at around £40 per tonne of CO_2 for existing housing and a five-year payback time for existing non-residential buildings. The White Paper also stated that future tightening of the EPN energy target may be possible as new technologies become available, subject to cost benefit analysis.

91. Energy use regulations in the built environment in the Netherlands were first introduced at the end of the 1970s. The 'Bouwbesluit' was first launched in 1991, and originally contained minimum thermal insulation requirements for the building fabric. In the mid-1990s the policy-makers identified the need for a more integrated approach that accounted for the total energy demand of a building, which resulted in the EPN performance standard being introduced in 1995. For new dwellings, the EPN was set at 1.4 in 1995, reduced to 1.2 in 1998 and then to 1.0 in 2000. A further reduction to 0.8 was discussed for introduction in 2004, but was dismissed on the grounds that the resultant additional construction costs would be excessive for apartment units, which are the main dwelling type in Holland (Jeeninga & Kets, 2004). However, though apartment houses consume little energy, there are still opportunities for further reductions in the energy consumption of detached dwellings, which it is anticipated will result in a further revision of the EPN target in the longer term (Jeeninga & Kets, 2004).

92. The Dutch Environmental Action Plan, which lasted from 1991 to 2000, established a range of financial incentives to improve the energy efficiency of existing, as well as new buildings. These included, for example, grants for the installation of high efficiency boilers and low-E glazing.

Denmark

93. Current Danish energy policy is outlined in the latest energy White Paper called 'Energy 21' (Danish Ministry of Environment and Energy, 1996). The main goal contained within this was a 20% reduction in CO_2 emissions by 2005. The paper also describes how the focus on delivering energy savings will be partly achieved through the introduction of more stringent building codes. In the previous energy White Paper (Energy 2000) the Danish Government had targeted itself with a reduction in the heat requirement of new buildings to 50% of the level at that time (1990) by the year 2000. The introduction of the 1995 building code resulted in only a 25% reduction – only half way to the stated target. Energy 21 restated the intention to revise the code in 2005 with more rigorous energy efficiency requirements, with the same objective to reduce the energy efficiency requirement in new buildings to a level corresponding to the 50% objective in Energy 2000.

94. The change in Danish government in 2002 resulted in a change of emphasis in relation to environmental, climate and energy policy. The new stated objective is to make environmental and energy priorities subject to more direct cost/benefit analysis. Some of the consequences of this were that almost all funding for research programmes on energy consumption was stopped (Bugge Garn, 2004), and an already-completed draft regulation for compulsory solar water heating on new housing was scrapped. However, the new government has kept the former administration's promise of a 30% improvement in building energy performance for 2005. The new government also has to produce an action plan on how to lower energy consumption in buildings before the end of 2004.

Switzerland

95. The present Swiss energy action plan 'SwissEnergy' (UVEK, 2001) was launched in 2001 and replaced the 'Energy 2000' programme that ran from 1991 to 2000. SwissEnergy summarises both energy policy objectives and the measures to be taken in co-operation with the cantons and the private sector. The key areas of the plan are energy use in buildings and transport, the economics of energy production and use, and promotion of renewables and energy efficiency. Many of the activities initiated under Energy 2000 will be continued. In SwissEnergy, the Swiss government has set targets to reduce consumption of fossil fuels by 10%, and to limit the increase of electricity consumption to 5% between 2000 and 2010. Heat production from renewables is planned to increase during the same period.

96. To replace the Decree on Energy Use of 1991, which expired at the end of 1998, a new Federal Energy Law entered into force in 1999. The Energy Law envisages measures to reduce energy consumption, and includes the following measures in the built environment:

   a) Cantonal legislation in the building sector (heat insulation, individual metering and billing of heating and hot water).

   b) Financial incentives for the efficient use of energy, renewable sources of energy and waste heat and promotion measures (information, advice, education, training, research, pilot installations, demonstration installations).

   c) It calls for more extensive co-operation with the private sector.

   d) Cantons are free to act independently (as long as there is no federal regulation) and gives priority to voluntary actions rather than regulations. It gives more responsibilities to the cantons in the field of regulations, in particular, for buildings.

97. The implementation of the CO_2 reduction targets is enshrined in the 'CO_2 Law', which came into force in 2000. This law has two stages of implementation. The first stage outlines a range of voluntary measures. The second stage envisages the

implementation of a CO_2 tax to be levied on fuels, which should be in place by the end of 2004 and have a maximum threshold of SF210 per tonne of CO_2 (£91/tCO_2). This is less than the level recommended by HM Treasury for 2002 (£70/tC or £257/tCO_2) (Clarkson & Deyes, 2002).

Germany

98. The German policy response to climate change is outlined in the national climate protection programme (BMU, 2000). The target for reduction in CO_2 emissions is 25% in 2005 compared to 1990. This exceeds the targets under the EU burden sharing agreement of 21% and Kyoto Protocol of 18%. The long-term commitment is a reduction of 40% by 2020. Both are consistent with the recommendation of the Enquete Kommission in the late 1980s for a cut in excess of 85% by the middle of the century (Anon, 1990). The household and building sector share of the 2005 target has been set at 18 to 25 million tonnes of CO_2 or 1.8 – 2.5%. In terms of reducing energy consumption in buildings, the main policy measure was the introduction of the more stringent EnEV building energy codes and energy labelling system. The government estimates that the EnEV ordinance will reduce CO_2 emissions by 10 million tonnes per year by 2005 and the resulting investment would create up to 90,000 new jobs. The German government has estimated additional building construction costs to be of the order of 1 to 2%, but that these would be offset by savings in the cost of heating energy. Other policies include investment grants and tax relief for the energy-efficient upgrading of existing buildings, and active promotion of the voluntary 'Passivhaus' standards (Feist, 1998). Germany also has a policy of promoting and subsidising renewable energy in the built environment. For example, the 100,000 roofs solar energy programme (aimed to install 300 megawatts of new photovoltaic solar capacity by the end of 2003), and a programme to promote solar collectors (there are currently over 4 million m^2 of solar thermal energy systems installed on German roofs).

Extent of compliance with regulations and impact on building control

99. In Denmark, the experience is that most buildings do comply with the code, despite relatively weak building control procedures (Bugge Garn, 2004). The actual energy performance of buildings built to the code is worse than expected due to the fact that most householders heat their buildings to around 22°C, rather than the 20°C internal temperature on which the calculations are based (Bugge Garn, 2004)[3]. Another issue is that most new buildings in Denmark are built with underfloor heating, which tends to be more difficult to control due to the long response times, and is often used for comfort reasons rather than space heating (eg warm feet).

[3] Differences between the internal temperature targets used in energy models, and the reality of how people actually heat their homes, need to be carefully considered.

The authorities have stated their intention to improve building control with the introduction of a physical check when the building is constructed.

100. In the Netherlands, there is no official research on the extent of compliance and real building performance. The general assumption is that most buildings do not meet the official standards, but that there are no major discrepancies (Jeeninga, 2004).

101. Problems of non-compliance in Germany are recognised, and as part of the climate change policy, the Länder will be required to improve enforcement of building regulations.

Feedback and evaluation of impact of regulations

102. The Dutch process for building control imposes very strict application of the energy performance calculation, with officers specially trained to check and monitor the calculations. Municipal control also includes procedures for monitoring the actual energy performance. Interestingly, although there are limits for airtightness, there are no mechanisms for checking or monitoring actual airtightness levels. Although leakage testing is not a standard procedure, what testing that has been done suggests that actual building airtightness is worse than as designed (Jeeninga, 2004). There have been some government-funded studies on the impact of the EPC, but these have been mainly qualitative in their nature. The assumption is that lowering the target EPC by a certain factor equates to energy consumption reduction by the same factor. Some empirical work in the Netherlands on energy efficient dwellings has shown that for a reduction in EPC from 1.2 to 0.7 the total energy consumption reduces linearly (Jeeninga, 2004). Some of the impacts of the regulations that have been identified are the cost increases (especially for apartments) and the required skill level needed to build houses to the standard (Jeeninga, 2004). One success story of the Dutch approach is that soft coat low-E glazing (HR++ in Dutch terminology[4]) has become the norm for buildings in the Netherlands.

103. The Dutch authorities conduct a survey on the condition of the national building stock every five years (known as the 'KWR'). This includes interviews with occupants as well as physical inspections. The last KWR was held in 1999-2001 with a sample size of 15,000 homes, and gave an indication of the energy efficiency of housing stock in 2000. The next KWR is expected to be conducted around 2005 and will give an indication of the impact of energy saving measures and changes to the building regulations (VROM, 2001b). It is not known how comprehensive the proposed physical inspections for 2005 will be, or whether the KWR is similar to the English House Condition Survey.

[4] The Dutch HR++ window specification equates to a whole window U-value of ≤ 1.6 W/m^2K.

104. In Denmark, there will be feedback via the energy labelling law, especially in the case of large buildings, where annual energy reports based on actual consumption are compulsory. The statistics from the scheme can be used to assess the impact of any regulation changes and the extent of compliance. There is not normally any physical checking of new buildings relative to the code (local authorities do have the powers to conduct such checks but rarely do so), and there is no tradition of air pressurisation testing (Bugge Garn, 2004). Some mortgage companies do make a physical inspection before approving financing.

105. The Swiss authorities have stated their intention to make random spot checks to ensure that buildings comply with the regulations.

106. No information has been identified that describes any monitoring or impact evaluation of the current thermal building regulations in Germany. The Bundesrat (upper parliamentary chamber) has requested that the government review the impact of the ordinance by the end of 2006.

Comparison of methodology of regulations

107. Table 10 summarises the categorisation of the energy regulations from the four countries according to the four different methodologies (unit-based elemental, overall average transmission loss, heat demand or energy use) and identifies any special features contained in the method. All of the regulations are in the process of conforming to the requirements of the EPBD and the EN 13790 standard.

Table 10 Summary of building regulation methodologies

Country	Regulation Methodology	Special Features
Denmark	Choice of elemental, transmission loss or heat demand.	Heat demand formula for dwellings contains no area dependent term. Regulation is split into two according to building size (<1,500 m^2 and ≥1,500 m^2).
Netherlands	Energy use (combined with maximum transmission loss).	Dimensionless target similar to SAP. Energy demand target related to envelope area and floor area. Target varies according to building type (13 non-domestic and two domestic categories).
Germany	Energy use (combined with maximum transmission loss).	Energy demand target related to shape factor (envelope surface area/ building volume). Building types are split into those that are heated above 19°C (dwellings, schools etc) and those with lower internal temperatures (12°C to 19°C).
Switzerland	Energy use (combined with maximum elemental values).	Heating demand limit related to shape factor (envelope surface area/heated floor area). Target varies according to building type (10 non-domestic and two domestic).

108. Three countries (Netherlands, Germany and Switzerland) use some form of energy use calculation. The relatively old Danish regulations consist of a choice of elemental, target U-value or heat demand calculation. Building shape is a factor in the energy target in the Dutch, German and Swiss codes. In the Danish regulations, shape is only a factor for large, non-domestic buildings. The Danish target for dwellings is influenced only by the number of storeys.

Other requirements

109. How the different regulations cover some of the other regulatory requirements, such as for ventilation and thermal bridging, is summarised in Table 11.

Table 11 Other regulatory requirements

Country	Denmark	Netherlands	Germany	Switzerland
Thermal Bridging	Effect of thermal bridges must be allowed for in U-value calculations (Danish standard DS418 describes procedures for doing this).	Calculation based on EN 10211-1/NEN 2778.	Full calculation of all thermal junctions and bridges using numerical modelling, or transmission loss U-value penalty of 0.1 W/m^{2}K for external elements, or transmission loss U-value penalty of 0.05 W/m^{2}K for external elements if the building design uses robust details.	Linear and point thermal bridges must be fully considered in the energy calculation. These can be modelled by simplified methods for commonly occurring thermal bridges, or by full computer modelling for more complex situations. There are limits for common thermal bridges.
Integration of Thermal and Ventilation Requirements	Allowances for ventilation losses in the heat demand calculation. Heat recovery compulsory for mechanical ventilation systems.	Calculation allows for ventilation losses (including auxiliary energy such as that for fans), heat recovery, humidification and cooling.	Ventilation losses accounted for in energy calculation. There is special provision for ventilation requirements when 30% glazing limit is exceeded to prevent summer overheating.	Calculation allows for ventilation losses and heat recovery.
Do Requirements Depend upon Source of Primary Energy?	Electrical heating not allowed (indirectly – due to regulations for supply of district heating and natural gas).	Primary energy conversion factors are important, making it difficult to conform to the regulations with electric heating due to the inefficient primary conversion factor.	Calculation uses primary energy conversion factors specific to the heating installations. Energy targets are different for buildings with electrically produced hot water.	Efficiency factor of heating installations taken into account.
Contributions from Renewables	Not considered.	Energy produced by photovoltaic systems is taken into account by offsetting the electricity produced against any electrical energy used for lighting, heating and ventilation. Solar hot water systems are also considered in the calculation.	Not specifically considered.	Not specifically considered.
Specific Provision for CHP or Heat Pumps	Not specifically considered.	CHP and other such energy sources are taken into account in the EPL calculation for building developments.	Not specifically considered.	Efficiency of heating installations taken into account in energy requirement, including heat pumps and CHP.
Use of Robust Details	None.	None.	Robust details for thermal bridging.	None.

Comparison of requirements with current and proposed UK regulations

Airtightness

110. A comparison of the requirements for airtightness is summarised in Table 12. With the exception of Denmark (which has no stated airtightness limit), the three remaining countries under study all have airtightness requirements (ac/h at 50Pa range from 1.3 h^{-1} to 5.2 h^{-1}) that exceed those required by the UK building regulations.

Table 12 Comparison of airtightness standards

Country	Regulation	Stated Airtightness Limit	Normalised Airtightness (ac/h at 50Pa) (Limb, 2001)
UK	ADL (2002)	Air permeability of 10 $m^3/h/m^2$ at 50Pa, recommended for dwellings, compulsory for non-domestic buildings (buildings >1,000 m^2 must be tested).	8.3 h^{-1}
UK	Possible ADL (2005) (ODPM 2003)	Air permeability of 7 to 10 $m^3/h/m^2$ at 50Pa.	5.8 to 8.3 h^{-1}
UK	Prototype 2008 Standard (Lowe, 2001)	Air changes per hour at 50Pa of 5 h^{-1}.	5 h^{-1}
Denmark	BR95 and BR98 (1995 and 1998)	No limit – "Buildings ... shall be so constructed that heat losses are not significantly increased as a result of ... unintended passage of air".*	–
Netherlands	Bouwbesluit (2003)	0.2 m^3/s at 10Pa (per 500 m^3 of building volume).	5 h^{-1}
Germany	EnEV (2001)	Must be 'state of the art' – Optional pressure test results of <1.5 h^{-1} for mechanically ventilated and <3 h^{-1} for naturally ventilated buildings allow a 15% reduction in the allowance for air infiltration heat losses.	1.5 h^{-1} to 3 h^{-1} (optional)
Switzerland	SIA 380/1 (2001)	0.7 m^3/s at 4Pa for dwellings (range of 0.3 to 1.2 for all building types).	3 h^{-1} for dwellings (range of 1.3 to 5.2 h^{-1})

* This appears to refer both to increases in heat loss caused by higher ventilation rates and to degradation of U values

U-values

111. Table 13 summarises the various requirements for elemental and target U-values in the different countries. These are compared to current UK limits as well as some proposed future limits.

112. A comparison of the current elemental maximum values under ADL1 (2002) is only possible with the Danish regulations, as this is the only one of the four countries investigated that still allows this form of compliance with thermal regulations for new buildings. The Danish targets are more stringent than those in the UK for all the main types of building element by around 10% to 20%. For example, the maximum U-value for windows allowable in Denmark is 1.8 W/m^{2}K compared to 2.0 to 2.2 W/m^{2}K in the UK, and the maximum allowable U-value for external walls in Denmark is 0.2 to 0.3 W/m^{2}K compared to a maximum of 0.35 W/m^{2}K in the UK. Germany has maximum U-value limits for new components in existing buildings, with the maximum for replacement windows at 1.5 to 1.7 W/m^{2}K, far exceeding the limit in the UK for new dwellings. In some cases, the nominal U-values understate the actual differences. For example, DS418 requires the inclusion of structural thermal bridges that are excluded from the calculation of U-values under ADL (2002).

113. In the case of maximum allowable U-values for elements when using target U-value, heat demand or energy calculation compliance approaches, the UK has the least demanding targets when compared to those in the other four countries. In Switzerland, the suggested target U-values are lower than the maxima allowed using the elemental approach in the UK, and lower even than the proposed elemental maxima in the prototype 2008 standard (Lowe, 2001). Of particular note is that the Swiss are suggesting that target U-values for windows should be 1.2 W/m^{2}K. This is a very demanding requirement that can be achieved with double-glazed windows only with the use of insulated window frames.

Table 13 Comparison of U-value limits

Country	Regulation (or Proposed Regulation)	Roof (W/m^2K)	External Wall (W/m^2K)	Ground Floor (W/m^2K)	Window (W/m^2K)	Whole Building Maximum (W/m^2K)
UK	ADL1 (2002) – Elemental Maximum	0.16 – 0.25	0.35	0.25	2.0 – 2.2	
UK	ADL1 (2002) – Target U-value/Poorest Acceptable	0.35	0.7	0.7	-	0.48*
UK	Possible ADL1 (2005) – Maximum Allowable (ODPM, 2003)	0.35	0.7	0.7	3.3	-
UK	Possible ADL1 (2005) – Maximum Average (ODPM, 2003)	0.25	0.35	0.35	2.2	-
UK	Prototype 2008 Standard – Elemental Maximum (Unit-based calculation) (Lowe, 2001)	0.16	0.25	0.22	1.3	-
UK	Prototype 2008 Standard – Maximum Allowable (Transmission Loss method) (Lowe, 2001)	0.3	0.19	0.26	1.56	-
Denmark	BR95 and BR98 (1995 and 1998) – Elemental Maximum (Unit-based calculation)	0.15 – 0.2	0.2 – 0.3	0.2	1.8	-
Denmark	BR95 and BR98 (1995 and 1998) – Maximum Allowable (Transmission Loss & Energy Frame)	0.25	0.3 – 0.4	0.3	2.9	-
Netherlands	Bouwbesluit (2003) – Maximum Allowable	-	-	-	4.2	0.4
Germany	EnEV (2001) – New Dwellings – Maximum Allowable	-	-	-	-	0.44 (Surface Area/ Volume = ≥ 1.05) to 1.05 (Surface Area/ Volume = ≤ 0.2)
Germany	EnEV (2001) – Existing Buildings New Component Maximum	0.25 – 0.3	0.35 – 0.45 (facade)	0.2 – 0.3	1.5 – 1.7	-
Switzerland	SIA 380/1 (2001) – Maximum Allowable	0.3	0.3	0.3	1.7	-
Switzerland	SIA 380/1 (2001) – Suggested Target Value	0.2	0.2	0.2	1.2	-

* Target U-value method using ADL1 2002 elemental values and average post-1996 UK dwelling dimensions (semi-detached house, 76m^2 floor area, 81m^2 external wall area (Johnston, 2003) unadjusted for boiler efficiency, solar gain or orientation).

Energy performance requirements

114. It is difficult to directly compare the energy performance requirements for the different countries due to the different methods used (heat demand versus primary energy versus CO_2 emission), and other factors such as whether lighting is included and the influence of the different house shape ratios used. Nevertheless, an attempt has been made to compare the energy thresholds for domestic buildings. PREDAC (2003) calculated target energy values for typical detached and terraced houses for the UK, Germany and the Netherlands, making certain assumptions[5] about the dwellings. These data are shown in Table 14, along with additional estimates for Switzerland and Denmark. It is possible that the differences between these figures are produced by differences in calculation assumptions – eg regarding internal temperature. The definitive test, which we have not been able to undertake in the course of the current study, would be to recalculate the performance of the UK dwellings using the methodologies of each of the other countries. Such an approach was pioneered in the 1980s (NAO, 1994) and demonstrated clearly that procedural differences in calculation frameworks could be as important as nominal difference in U-value.

Table 14 Comparison of estimated energy performance requirements

Country	Regulation	Terraced House (kWh/m²/a)	Detached House (kWh/m²/a)
UK (PREDAC, 2003)	ADL1 (2002) – SAP carbon emissions method	108	117
Netherlands (PREDAC, 2003)	Bouwbesluit (2003)	125	140
Germany (PREDAC, 2003)†	EnEV (2001)	140	153
Switzerland‡	SIA 380/1 (2001)	99	99
Denmark§	BR98 (1998)	113	113

† German figures include an additional 10 kWh/m²/a for lighting.

‡ Swiss energy requirement based on dwelling with an estimated (A/EBF) ratio of 2.0, plus an estimate of 10 kWh/m²/a for lighting.

§ Based on Danish heat demand limit plus an estimate of 10 kWh/m²/a for lighting and 25 kWh/m²/a for hot water.

115. The most demanding regulations in terms of primary energy demand for dwellings are those from Switzerland, with a target estimated at 99 kWh/m²/a. The UK and Denmark have similar primary energy limits (estimated at around 110 – 115 kWh/m²/a), with the Netherlands having slightly higher requirements at around 125 to 140 kWh/m²/a. The least demanding energy requirements for domestic buildings are those in the German EnEV regulations where the energy limits for domestic buildings are of the order 140 – 150 kWh/m²/a. The relatively low demands of the German regulations are somewhat surprising given the high German share of carbon

[5] PREDAC (2003) assumptions include: dwelling size 100 m², 75% boiler efficiency, four persons per dwelling, allowance of 10 kWh/m²/a for lighting and 25 kWh/m²/a for hot water when not included in regulation.

reduction under the EU burden sharing agreement, and suggest that the emphasis of German energy policy is oriented towards other sectors such as transport and primary energy generation.

116. It is of interest that Denmark actually raised the maximum heat demand limit by 30 MJ/m^2/a (equivalent to 8 kWh/m^2/a) in amendments to the original 1995 and 1998 regulations. The original regulations had a heat demand limit of 250 MJ/m^2/a, which was subsequently increased to 280 MJ/m^2/a in the amendments. The reason for the change was the inclusion of thermal bridging calculations and requirements in the amendments. For example, heat loss through foundations was increased in the new calculation procedure and also had a specific maximum requirement. The effect of the increase in the heat demand limit was to make the influence of the new procedures neutral on the real energy performance of the building.

Some key observations

117. The German, Swiss and Dutch regulations already use an energy use calculation compliant with EN 13790 to determine the thermal performance of buildings. The Danish regulations will be changed to an energy demand calculation based on EN 13790 sometime in 2005.

118. None of the countries express the energy performance target in terms of CO_2 emissions. The energy use targets for Germany and Switzerland are expressed in energy (kWh or MJ) per m^2 usable floor area per annum. The Dutch energy target is expressed as a dimensionless measure (the EPC), which is the characteristic energy use of a building divided by the standardised energy use, and is designed to represent the energy use of an average size Dutch terraced house. The Danish heat demand target is expressed as MJ per m^2 of usable floor area per annum.

119. The stated primary objective of the building energy performance regulations in all four countries is energy saving as part of each country's commitment to CO_2 emission reduction.

120. Building energy reduction targets are linked to national energy and climate change policies and form an integral part of efforts to meet objectives under the Kyoto Protocol and EU burden sharing agreements.

121. The regulations in all four countries make allowances for thermal bridges and ventilation losses in the energy calculations. Requirements for thermal bridging go beyond what is required under ADL (2002).

122. In some of the countries (in particular, the Netherlands and Denmark), shifts in the emphasis of energy policy appear to have qualified clear trends to introduce more

stringent building energy regulations over time, with a more rigorous assessment of the cost-effectiveness and economic impact of proposed changes before introducing new energy codes.

123. The main emphasis of both policy and codes is towards new buildings, although it is recognised that more needs to be done to improve the energy performance of existing buildings.

124. There is relatively little monitoring of actual performance and there has been little or no attempt at empirical verification of the impacts regulation in any of the countries studied. There are some indications that this is perceived as an important issue in Germany.

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