Chapter 2
House Rating Schemes

This chapter presents selected House Energy Rating Systems in diverse contexts and explores the different aspects of a House Energy Rating Scheme (HERS). It demonstrates that there are inadequacies in the current rating schemes which this book attempts to address.

2.1 House Energy Rating Schemes (HERS)

The *energy* rating of a house is a standard measure that allows the energy efficiency of new or existing houses to be evaluated, in order that dwellings may be compared. The comparison is commonly performed on the basis of the energy requirements for the heating and cooling of indoor spaces. Some of the HERS include all energy requirements, such as energy for water heating, washing machines and cooking.

Energy is not the only criterion for house evaluation in all rating schemes. Criteria are determined on the basis of the purpose of the rating. Other criteria that have been used as important parameters in building evaluation systems are the production of greenhouse gas (GHG) emissions, indoor environment quality, cost efficiency and thermal comfort.

The energy rating of a residential building can provide detailed information on the energy consumption and the relative energy efficiency of the building. It is performed through standard measurements carried out under specific regulations and experimental procedures by specialists (Santamouris, 2005). Overall, HERS can facilitate informed decision-making for all stakeholders, as well as home-buyers considering mortgages. The main impetus behind most of the rating systems has been to inform consumers about the relative energy efficiency of homes, in order to encourage home-owners to use this information in making their purchasing decisions (SRC, 1991).

HERS are found in a variety of forms:

- prescriptive
- calculation-based
- performance based

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All of those evaluate building performance within the scope of a program that has been developed by the authorities of a country to promote efficiency in building design. *Prescriptive* schemes provide minimum standards for the materials, equipment and methods of efficient design and construction that must be met to qualify for an energy efficiency rating. *Calculation* based ratings employ computer based models to predict a building's performance relative to that required in order to qualify for a rating under the program. *Performance* based ratings utilize actual building energy consumption data to evaluate building energy efficiency, which is then compared with the required standards of the program.

Prescriptive and calculation schemes are predominant, whereas performance based rating schemes are very rare because of the time-consuming nature of the system, which requires an extensive effort. Performance based schemes are also not applicable to new buildings because of their limited value as a tool for predicting performance and encouraging improvements prior to construction.

Rating schemes are generally associated with either *certification* or *labelling*. The former refers to the evaluation of building performance at the design stage, while labelling assesses in-use performance of the building when it is compared with other similar buildings.

The schemes vary in practice, from simply a paper-based check-list, to full thermal simulations. A good example of a paper-based check-list is the Model Energy Code (MEC) (Andersen et al., 2004), which was developed for the Department of Energy Building Standards and Guidelines Program in the United States. MEC focuses on the insulation of the envelope and windows of a building, the cooling and heating system, the water heating system, and air leakage. Most of these rating schemes use a grading scale to score buildings. One hundred point scales and star rating systems are common, while some use either a pass/fail system, or simply classify by terms such as bronze, silver, or gold. MEC is a simple pass or fail scheme (US Department of Energy, 1995).

Generally, all developed rating schemes around the world appear to be similar in their objectives, but different in programming and details. A general review of developed HERS has shown that these schemes are particularly widely implemented in the USA. The following section reviews HERS programs that have been actively implemented in the United States, Europe, Canada and Australia.

2.1.1 The United States of America

Energy rating schemes have been used in the USA since the 1980s (Santamouris, 2005). Over the past years a range of rating schemes has been implemented by the different states, cities, utilities and vendors. There are a variety of efficiency certification programs and numerous tools for analysing building performance.

Among the various schemes, the Energy Rated Homes of America is predominant, as it is currently operating in more than 18 states, with other schemes in continuous development in the other states. This scheme uses a 100-point scale of efficiency, divided into ten categories of stars (from one star, one star plus, to five stars plus). A higher star represents a house with better energy efficiency. The energy efficiency rating in this system expresses the predicted energy consumption, which is represented in the form of normalised annual energy consumption. The dependency of this rating system on a calculation of the amount of energy consumed means that the use of efficient appliances results in a more favourable rating than that for an efficient architect designed house, whereas arguably a free running house should have priority for reducing energy consumption.

Numerous software programs have been developed to foster increased energy efficiency in the building sector. In North America alone there exist about a hundred building energy tools serving a diversity of users (Mills, 2004). Many of these are applied to rate buildings, such as AkWarm, Building Greenhouse Rating, LEED, CHEERS, RECA 2000, Kansas, HOT 2000, Ohio, REM/Rate, TRET, Energy Gauge USA, T. A. P, BESTTEST, HEED, Colorado and E-Star.[1]

The main objectives of the Home Energy Rating Schemes implemented in the USA are: affordability (a higher quality and more comfortable home for less money), qualifying for a more favourable mortgage loan, and environmental protection (through optimizing residential and commercial energy and indoor environmental performance). The association of home energy rating systems, with a scheme called Energy Efficiency Mortgages, brought about the penetration of this rating system into the residential market (Santamouris, 2005). The mortgage industry uses existing energy audits to make loans for energy improvements (Barbara, 2000).

2.1.2 Canada

The Office of Energy Efficiency (OEE) has developed and promoted a wide range of programs in Canada. These are aimed at improving energy efficiency in the energy sector of the Canadian economy, at conserving energy resources, aiding financial savings and reducing greenhouse gas emissions.

Home energy rating systems for houses in Canada, which began in 1997, were based on the report "Efficiency of Natural Resources Canada" (NRCan). There are two national energy rating programs for residential buildings, named Ener-Guide for Houses (EGH) and Ener-Guide for New Houses (EGNH). These governmental programs use HOT2XP and HOT 2000 as their rating tools. The tools are programmed to make a comparison for rating purposes of each house, with reference to houses of a similar size in a similar climatic region. To factor out the influence of occupants on energy consumption, standard operating conditions are used in calculating the rating. The energy rating assessment begins with a site evaluation, using a blower

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[1] More details about software programs can be found in the web-based references given by the US Department of Energy, 2009: *Building energy software tools directory,* <Energy Rated Homes of America US Department of Energy. http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm.

door test to measure the rate of air leakage in homes. The space heating and cooling systems and domestic hot water supply, appliance usage, and mechanical systems are analysed to produce an energy efficiency rating based on the home's annual energy consumption, on a rating ranging from 0 to 100 (Allen, 1999). The lower rating on the scale indicates high leakage, no insulation, high-energy consumption and therefore an uncomfortable home to live in.

Two standard bases for evaluating buildings are R-2000 standards[2] and the Model National Energy Code of Canada (MNECB).[3] To meet Canada's specifications Code, a house needs to be rated within the 80–85 range to comply with R-2000, or in the 70–75 range to comply with MNECH (Allen, 1999). The softwares used for analysing a building's performance are: HOT 2000, HOT 3000, HOT2XP, HOT2EC, EE4, GBtool and BILDTRAD. All can evaluate the energy performance of a building, but are unlikely to be applicable for a free running house evaluation.

One program used for the Canadian homes rating system is LEED. This rating system is an adaptation of the US Green Building Council's LEED Green Buildings Rating System, tailored particularly for Canadian climates, construction and regulations. This rating system measures the overall performance of a home in eight categories: Innovation and Design Process (ID), Location and Linkages (LL), Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Material and Resources (MR), Indoor Environmental Quality (EQ), Awareness and Education (AE). The rating system works by requiring a minimum level of performance through prerequisites, and rewarding improved performance in each of the eight categories. The performance level is indicated by four grades: Certified, Silver, Gold and Platinum, based on the number of points gained (between 45 and 136 points) (Canada Green Building Council, 2009).

2.1.3 Europe

Following the energy crisis in the 1970s, preliminary steps for energy saving measurements in Europe occurred in Sweden. Since 1993 a "Specific Actions for Vigorous Energy Efficiency Directive" has been employed throughout the countries in the European Union (Cook et al., 1997). The aim has been to "certify" the energy efficiency of homes. Since the directive neither specifies the certification

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[2] The R-2000 Standard is based on an energy consumption target for each house, and a series of technical requirements for ventilation, air tightness, insulation, choice of materials, water use and other factors (See: http://oee.nrcan.gc.ca/residential/personal/new-homes/r-2000/About-r-2000.cfm?attr=4).

[3] [MNECB] is intended to help in designing energy-efficient buildings. It sets out minimum requirements for the features of buildings that determine their energy efficiency, taking into account regional construction costs, regional heating fuel types, and costs and regional climatic differences. The MNECB has, in addition to sections on the building envelope and on water heating, detailed information on lighting, HVAC systems and electrical power, which can offer major energy savings (See: http://irc.nrc-cnrc.gc.ca/pubs/codes/nrcc38731_e.html).

procedure, nor identifies the kind of energy that should be assessed, the states were requested to prepare their own national methodologies (Santamouris, 2005), and each member country has produced a different interpretation of the term “certification”. The European Energy Commission then put forward a proposal for a new specific directive on the energy rating of buildings (based on “Energy Performance of Building Directive (EPBD) 2002/91/EC 16”). The EU adopted EPBD, which provided a common methodology for calculating the energy performance of buildings, and set minimum efficiency standards for residential and commercial buildings. The directive then introduced an energy performance certificate to promote greater public awareness. However, there are still no standards for the energy performance of existing buildings in the EU.

A review of the energy ratings of dwellings in the European Union by Miguez et al. (2006) describes the various rating systems in EU countries. Current rating systems, based on several regulations, all aim to save energy and reduce greenhouse gas emissions. These rating systems assess a building as to whether it complies with regulations. A range of techniques has been developed for such building assessment, and all are based on an experimental protocol for collecting energy data and theoretical algorithms to normalize total energy consumption for classifying buildings. Total energy consumption results from heating, hot water supply and lighting. Because of high heating energy requirements, all the member states in the EU have introduced compulsory maximum levels for coefficients of heat transmission in new buildings. The cold climate in these countries demands more insulation generally, meaning lower energy losses and GHG emissions.

Although the preliminary steps for energy saving and efficient energy use in the building sector were taken in Sweden, this nation still has no official energy rating system for buildings. However they do have stringent regulations. Among different rating systems in the EU, Denmark’s is known as the system which provides full energy rating, in the sense of awarding a graded score to buildings. The ratings developed in the UK and Denmark are discussed in more detail below, as they are the two pioneering rating systems in the EU.

2.1.3.1 United Kingdom

The oldest HERS exists in the United Kingdom. It mainly aims to decrease energy consumption and GHG emissions. Two house energy-rating schemes are currently operating in the UK. The National Home Energy Rating scheme (Hasson et al., 2000) was developed and implemented by the National Energy Foundation, an independent charitable trust (Turrent and Mainwaring, 1990). This scheme measures the thermal efficiency of dwellings in terms of energy running costs on a scale of 0–10. The rating procedure is carried out through the use of a computer program based on the Building Research Establishment Domestic Energy Model (BREDEM). This is used in different ways as the basis of the Standard Assessment Procedure (SAP), National Home Energy Rating (NHER) and $C0_2$ Dwelling Emission Rate (DER) (Energy Efficiency Partnership for Homes, 2006). In BREDEM the energy usage of a house is calculated on the basis of a description of its dimensions, insulation and heating system.

The Standard Assessment Procedure (SAP) has been developed by British planning authorities as the principal basis for labelling and house rating. It was drawn up to define the method of energy rating of residential buildings (Miguez et al., 2006; Richalet and Henderson, 1999). Energy rating is based on energy balance and cost for space and water heating per square meter of floor area, assuming average occupancy patterns. It includes details of the house, such as the heating system, thermal insulation, ventilation characteristics and the type of fuel used for heating, as factors affecting energy efficiency. Fuel costs and gas emissions are assessed, and on the basis of this individual suggestions for improvements are given. This rating does not consider lighting and domestic appliances in the process of calculating energy consumption, and it ignores the location of the building for the rating purpose. These omissions would appear to have a significant effect on the accuracy of the rating system, and to potentially discriminate against the value of a building design which might be suitable for a particular location and climate.

As there were doubts about its ability to achieve the target of energy saving and reduction of GHG emissions in the building sector, the SAP regulations were revised in 2001 (DEFRA, 2005). Nevertheless, as the basis of the methodology for improving the energy efficiency of buildings continues to be the calculation of energy consumption, it may well not be accurate in providing passive energy measurements, as demanded by Association for Environment Conscious Buildings (AECB, 2006), and is unlikely to grade passive architecture designs accurately.

NHER measures the energy efficiency of houses as a function of energy running costs per square meter. It calculates energy usage by taking into account the house details, including house location, design, construction, water heating system, cooking, lighting, ventilation and appliances. To calculate the rating, a standard occupancy scenario is assumed, in which the number of occupants is estimated from the house floor area and standard heating patterns. Thermostat settings and the period of occupation are also included as part of the standard. The actual occupancy data can be used to estimate the running costs, fuel use and emissions, but this will not alter the rating.

2.1.3.2 Denmark

As a pioneer in energy rating in the EU, Denmark started energy saving measurement in 1981. This country established a different type of energy audit, known as the "Act on the Promotion of Energy and Water Conservation in Buildings" (Energies-Cites, 2003; International Energy Agency, 2003). It comprises energy certificates for large and small buildings as well as for industrial buildings, and for CO_2 emissions in industry (Miguez et al., 2006).

The rating system is based on an energy inventory recorded by a qualified specialist. It includes three parts. The first part reports on water and energy consumption and CO_2 emissions per annum as compared with other similar buildings, on a rating scale from A1 to C5 (maximum to minimum efficiency). An energy plan is the second part of the system, through which ways for saving energy and water in buildings are proposed, with an estimation of the costs involved, and annual savings for each one. The final section of the rating provides information on the current state of the building in terms of its size, heating system and energy usage, and the cost of energy and heating.

This rating system appears to be sufficiently comprehensive for conditioned buildings but it is not able to deal with rating free running houses, owing to its dependency on the energy base.

2.1.4 Australia

House Energy Rating Schemes have also been introduced in Australia, with the same objectives as those in the other mentioned countries. The main objectives are to decrease residential energy consumption and greenhouse gas emissions, and to increase thermal comfort by encouraging improved building envelope design (Ballinger, 1998a).

Where the Australian climates differ from those of Europe and Canada, differences in the programming of HERS in Australia were expected. “It has been shown in many studies that passive solar design and energy conservation techniques are very cost-effective in Australia. Australian climates allow us to enjoy the outdoor generally throughout the year except on days of temperature extremes” (Ballinger, 1988, p 67). The moderate climate of some regions in Australia makes passive architectural design such as free running houses a good option, and most suitable for achieving the objectives of HERS. However, house ratings in Australia, as in other countries, are based on the prediction of energy requirements, and have not been modified to give more value to free running houses.

The Five Star Design Rating was the first energy-rating scheme, developed in Australia in the 1980s by the GMI Council of Australia. It was adopted for use in Victoria, New South Wales and South Australia. “Five Star Design Rating” (FSDR) is a form of certification available for dwelling buildings which comply with a number of requirements for energy efficient design. The design principles of a five star home under this system were based on the three basic elements of glass, mass and insulation (Ballinger, 1988). However, this system was not widely accepted by the building industry, because of its restrictive guidelines and its limitation to a single pass/fail rating.

During the 1990s, individual states in Australia attempted to develop their own House Energy Rating Schemes (HERS) to meet particular needs (Ballinger, 1991; Gellender, 1992; Wathen, 1992). Among the different schemes, the Victorian scheme, based on a computer program, was found to be the most effective; however, it was not flexible enough for all climates, particularly for warm humid climates such as in Queensland. It was therefore thought appropriate to develop a nationwide HERS.

The development of a nationwide House Energy Rating Scheme (HERS) was started in 1993 on behalf of the Australian and New Zealand Minerals and Energy

Council (Ballinger and Cassell, 1994; Szokolay, 1992b). The aim was to create a simple rating for energy efficiency for each dwelling throughout different climate zones and conditions in Australia. A graded five-star rating system was used to categorize the relative energy efficiency of dwellings, using a computer program based on the CHEETAH (engine), which was developed for the rating assessment (Ballinger and Cassell, 1994).

HERS predict the demand for the heating and cooling energy required to maintain conditions of thermal comfort inside a building, and rate the building's average energy consumption per square meter (MJ/m^2). Predictions are based on the extensive research and development embodied in CHEENATH, the core energy software model developed by CSIRO as suitable for Australian climates (Ballinger, 1998a). This engine, which is a significantly enhanced version of the CHEETAH engine, is the current basis of most modelling systems, such as NatHERS, FirstRate and Quick Rate, BERS, Q Rate and ACTHERS, which have been developed in different states. NatHERS and BERS simulate the operational energy usage in a home by running CHEENATH directly (with different user interfaces), while FirstRate, QRate, ACTHERS and Quick Rate are correlation programs, which do not carry out simulations.

AccuRate is the latest tool developed for HERS. It addresses some of the limitations in the NatHERS software and is now a replacement for NatHERS. More details regarding this are presented in Sect. 4.1.2.2.

At the time when NatHERS was created, it was assumed that this software would be developed in the future on the basis of comfort achieved without the use of heating and cooling (Ballinger, 1998b). However this project still remains incomplete, even in the latest developed tool for HERS.

2.2 Rating Methodologies for Buildings

Buildings present many characteristics that need to be taken into account for an appropriate evaluation and rating scheme (Roulet et al., 1999). Thus a wide range of rating methods has been developed.[4] Each method considers a number of parameters and criteria to assess buildings on a particular basis. These include perceived health, the provision of thermal, visual and acoustic comfort, indoor air quality, cost effectiveness, environmental impact and energy efficiency. However, energy efficiency is seen as the main parameter in almost all current building rating schemes, even in those which aggregate and evaluate buildings on the basis of a multi-criteria method.

The various methodologies developed to evaluate the energy efficiency of buildings are principally based on predicting energy consumption to assess a building, in order to certify the level of the building's performance (Santamouris M., 1995; Boland et al., 2003; Richalet et al., 2001; Santamouris, 2005; Santamouris and

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[4] Some of these methods appear in a review by Kotsaki, K. and G. Sourys (2000).

Dascalaki, 2002; Santamouris et al., 2007; Zmeureanu et al., 1999). The method is the same whether the building is residential or contains office space.

A historical review by Fairey et al. (2000) of the national HERS methods used in the US describes the following four proposed methods for rating the energy efficiency of homes:

- the original method
- the equipment adjustment factor method
- the modified loads method
- the normalized modified loads method.

Each method was developed to overcome shortcomings in the previous method. In the *original method* the score of a home depended on the fraction that the total estimated purchased energy consumption of the house represented of that for a reference home.[5] The dependence of this method on the fuel type involved represents a “flaw” in the method. This “flaw” is due to the “floating” value of the reference house, whose value could change as the function of a selected fuel type, and consequently the score of a home could simply change. This problem was solved through the second method, by adding an *equipment adjustment factor*. However, the main issue with the second method was that “rating directly by energy consumption misrepresents the relative value of envelope efficiency measures with respect to equipment efficiency measures” (Fairey et al., 2000, p. 4). *The modified loads method* was then developed to avoid the above problem. In this method, building loads[6] were used instead of energy consumption, to establish the rating fraction used in the original method. Since the load on building end uses does not change as a function of fuel, the “floating” problem was also solved. However, the presence of a “fuel neutrality flaw” was a problem with this method, due to the fact that different fuel types may be discriminated against in marketing. A “normalized modified load method” was then proposed that reflects differences in potential equipment improvements.[7]

The first two methods rely on the calculation of energy consumption, while the last two refer to the amount of energy load. Although the second basis is more reliable, both bases have the shortcoming that they are unable to exactly predict actual energy consumption and energy load, because certain variables such as occupancy and the behaviour of occupants could change the results of the calculation.

Botsaris and Prebezanos (2004) introduced a method for the certification of the energy consumption of a building by recording its “energy behaviour”. In this

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[5] A home score in the original method was calculated from 100 to 20*(ER/EC), in which ER is the total purchased energy consumption for heating, cooling and hot water for the rated home, and EC is that for the reference home.

[6] Load in this method is defined as the amount of heating energy that must be added or removed from a building to satisfy a specified level of comfort in the building, and Energy Use is the amount of energy required by the equipment that satisfies the load.

[7] The mathematical process is described in Fairey et al. (2000).

method energy indices, such as the Index of Thermal Charge (ITC) or Index of Energy Disposition (Andersen et al., 2004), are employed to simulate the heat losses of the building, and the heat flow due to temperature difference between the indoor and the outdoor space. This work is based on an interpretation of the behaviour of the energy sources, such as the operation and cessation time of the sources. Cessation times can be predicted relatively reliably for office buildings with a clear occupation time. However, this method for residential buildings may not be accurate, owing to the variability of its occupants' activities. The method can, however, help to accurately predict the energy consumption of residential buildings if it is adapted to include *multiple occupancy scenarios*.

A review of the latest developments in the field of the-energy rating of dwellings, mainly in Europe, describes the theoretical and experimental techniques for energy characterization of buildings that have been employed (Santamouris, 2005; Miguez et al., 2006) and shows that all of the systems have been developed basically to predict the total energy demand of a building.

EUROCLASS is a recent method developed for the energy rating of buildings through the European SAVE program. It suggests a theoretical technique that comprises all specific energy uses and treats energy normalization in a new manner. It proposes a new framework based on the use of "the relative frequency distribution curves for the different end users of the energy" (Santamouris, 2005, P71). The variables which are determined to grade a building are "total supplied energy" (kWh/m^2) and "total delivered energy" (kWh/m^3). These variables can be obtained from two protocols: the Billed Energy Protocol (BEP) and the Monitored Energy Protocol (MEP). Each of these protocols provides useful information for carrying out a rating test of a building in a specific comparison scenario. EUROTARGET is the software developed within the frame of the EUROCLASS project to apply this proposed rating methodology for dwellings.

There are a number of studies that propose multi-criteria for a building assessment and rating scheme. These studies include a number of parameters to rank buildings, such as energy use for heating and cooling, indoor environment quality, cost, impact on the external environment and the life-cycle of the embodied energy of construction (Roulet et al., 2002; 2005; Soebarto and Williamson, 2001).

In the study by Soebarto and Williamson (2001) a methodology based on a weighting method was developed to assist the building design process and assess a building's environmental performance in accordance with multi-criteria assessment. This methodology converts the criteria into a two criteria problem by creating a weighted sum of benefits and costs for each solution. These two functions are normalized to reflect the average weighting value. An environmental performance assessment tool, ENE-RATE, was developed on the basis of this method to perform environmental ratings. Although this study accepts that thermal comfort in an unconditioned building should be considered as a criterion for building evaluation, it does not clarify any method of incorporating that criterion for that purpose.

Roulet et al. (2002) produced a multi-criteria ranking methodology to rate office buildings. The method employs fuzzy logic on a set of indices, each of which addresses a particular aspect of building performance in the two categories of energy and comfort. Using a principal components analysis, the energy and comfort parameters are combined in a single indicator that globally characterizes the performance of the building. Annual energy use for heating, cooling and lighting (kwh/m^2) and discomfort hours during winter and summer (h) are the criteria used to define this single indicator. The proposed criteria for indoor environment quality are: predicted percentage of dissatisfaction based on the Fanger comfort model,[8] outdoor airflow rate per person, and noise level in the working place. Each parameter is given a weight depending on the scale of values of the user of the method. This method would not appear to be successful in evaluating thermal comfort conditions in a naturally ventilated building, because the employed criteria are only applicable for conditioned buildings. The method can be adapted for use in any multi-criteria rating scheme.

Regardless of the function of a building, *normalised energy use* is seen as the most common method to evaluate the efficiency of a building in the conditioned operation mode (Chung et al., 2006). This method regards the building's size and annual energy use, divided by the conditioned floor area or by volume. There are shortcomings in this method which make it unrealistic for addressing the efficiency of an architectural design. This will be discussed later in Sect. 2.4.3.

2.2.1 Building Rating Features

Almost all of the rating schemes address the features of the building's envelope and the efficiency of equipment for cooling, heating indoor space, and hot water supply. Some of them include energy related fixed components such as washing machines, dishwashers, refrigerators, freezers and dryers. Current tools employed for rating systems have the capability of calculating heating, cooling, hot water, lighting, and appliance energy loads. Some of them also predict the energy cost of new and existing single and multifamily homes, on the basis of the prediction of total energy requirement, the type of fuel used, and the efficiency of appliances. Occupancy factors have usually been considered as a default or are standardized; however, a limited number of ratings tools are flexible enough to change the occupancy variables, such as the number of occupants and the hours of occupation.

There are many similarities between the different systems. They all use some combination of data collection and calculation to present information to building users about energy consumption. Their reliance on calculation is almost inevitable because of the highly disparate nature of buildings. This utility metric method is, however, limited in its accuracy, because the amount of energy consumption is so dependent on occupants' preferences and occupation time.

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[8] The Fanger thermal comfort model will be discussed in Chap. 3.

2.3 Energy as the Main Parameter for Rating Buildings

Energy efficiency is a critical issue for high quality housing. Energy as a measurable variable not only represents a high percentage of the running cost of a building, but also has a major effect on the thermal and optical comfort of the occupants.

In some climates it is difficult to have a comfortable indoor condition without an energy load. As the energy rating of a building can provide specific information on the energy consumption and the relative energy efficiency of the building, it is then possible for a potential buyer to have information on the energy bills that are likely to arise. Through this information the owner of a house may also be able to identify and pinpoint specific cost-effective improvements. However, in a moderate climate a successful passive architectural design could provide thermally comfortable conditions, in which occupants do not need heating and cooling devices. In this case the current energy based rating scheme may fail in its assessment of a building's performance.

Whilst environmental issues were the main reason for developing HERS, financing and marketing have become the major motivations for promoting it. A highly rated building on the market may be eligible for special recognition through a series of voluntary or compulsory programs, which increases its value for sale or rental income. Through HERS, energy-efficient financing is achievable because energy-efficient houses cost less to operate. For the promotion of HERS, the market needs a measurable basis for HERS which is attractive enough for the public to apply for it. Energy and comfort are two parametric options for this purpose, which are related to each other. Energy, as an expensive parameter, would appear to be the more appropriate basis for HERS for marketing purposes, although the provision of comfort may actually be more expensive. However, in modern society in which the public are increasingly dependent on energy for the provision of thermal comfort, energy is seen as a preferable parameter as the basis for HERS.

Connecting HERS and mortgage incentives for energy efficient development has affected the rating systems in the US (National Renewable Energy Laboratory Washington, 1992). HERS provides standardized information on the energy performance of homes, and energy-efficient mortgages (EEM) provide a financing mechanism for energy efficiency. The estimation of energy costs generated by a reliable HERS is a valuable source of information for facilitating EEM. This objective has led to the combining of cost- effectiveness and energy efficiency, and so great attention has been paid to house ratings based on energy usage and its costs.

In addition, predicting ratings on an energy basis helps to choose appropriate HVAC equipment where heating and cooling plants are a part of building construction. This creates an opportunity to optimize heating and cooling plants, and also allows for competition in the market to refine the rated capacity of the size of plant (Hunt, 2003).

The Australian marketing of rating systems is different from that in the US, the EU and Canada. In these countries rating schemes have been employed to support different financial arrangements, while in Australia sustainability and environmental impact are the main policy drivers of the building rating schemes. Moreover in

Australia, with most of its population living in its moderate climate zones, HERS is more amenable to independence from energy and to the provision of thermal comfort as its basis.

2.4 Issues Related to Building Energy Rating Schemes

2.4.1 Rating and Achievement of Sustainability

Current rating schemes have not been sufficiently complex to address the main issues of sustainability. It has been argued in the "design paradigm" that buildings can reverse their environmental impact, and can even have positive impacts over their whole life cycle. This requires integrating conditions for ecosystem preservation in the building fabric. General ecological criteria must then be added to any assessment system for sustainable development. However, current building assessment tools provide only limited support for this issue (Chau et al., 2000). Sustainability is a design problem rather than a technical problem, but the current rating systems are not based on design criteria. Instead, the emphasis is on predicting the negative impacts of a proposed design, such as the level of energy consumption, energy cost and GHG emissions. To move toward sustainable development, Birkenland (2002) proposed that a building must be designed to interact with its context beyond the exterior envelope of the building. It appears that no rating system based on an assessment of energy usage includes all ecologically relevant parameters; not even multi-indicator ratings, such as those described earlier in Sect. 2.2. However, a few include embodied energy, which is a technical aspect that can affect the ecosystem. This is one of the reasons for light-weight buildings being undervalued in the current rating system, while such buildings could actually contribute to improving sustainability.

2.4.2 Rating Free Running Buildings

Free running buildings cannot be accurately evaluated by the current rating schemes. Because all existing rating systems assume buildings to be artificially heated and cooled, they do not deal at all with free running buildings.

When comparing the actual performance of an occupied free running house with the predicted performance by a rating scheme, Soebarto (2000) demonstrated a low score from the rating, although her study shows that the house in question performed reasonably well in terms of its indoor comfort condition, energy use and environmental impact. This reflects the inability of rating systems to assess free running buildings adequately. The benefits of passive architecture design, therefore, may not be properly evaluated, because of the independence of such design from energy use. Another study on the thermal performance of three award winning houses in Australia (Soebarto et al., 2006), illustrated that the houses did not conform to comfort standards and national regulations, in addition to achieving an unacceptable score in the mandated regulatory rating scheme, while at the same time the occupants of all the houses were largely satisfied with the houses' thermal performances.

These two studies imply that there is a difference between an efficient design for a free running house, and that for a conditioned house. This issue is examined in Chap. 4.

2.4.3 Rating Index

Regardless of which method is applied for HERS, an adjusted energy indicator is employed as an indicator of efficient building design. The chosen indicator plays an important role in the reliability of the rating designed to assess the thermal performance of buildings.

Although energy minimization is promoted as an energy efficient building strategy (Boland et al., 2003), low energy usage does not necessarily indicate design efficiency (Sjosten et al., 2003; Olofsson et al., 2004). Energy consumption can be relatively low because the building is not occupied most of the time, or the building amenities are low. Low energy consumption can also be due to efficient appliances. Since appliances consume a significant proportion of the energy used in a home[9] (Environmental Protection Agency, 2000; Office of Energy Efficiency, 2005), highly efficient equipment can reduce the total energy requirement. This means that the energy demand of a building can be reduced by using more efficient appliances, rather than by improving building design.

Furthermore, a *normalized* energy based rating is not sufficient to convey the credibility of an energy efficient design. This point has been argued in many studies (Soebarto, 2000; Williamson, 2000; Meier et al., 2002; Kordjamshidi et al., 2005a). The concept underlying the definition of energy efficient indicators for policy purposes is discussed in Patterson (1996) and Haas (1997). They show that normalized energy use is typically derived as annual energy used, divided by the conditioned floor area or volume. On the basis of this index, a smaller house achieves a poorer value than a similarly constructed larger house (Thomas and Thomas, 2000), where in reality reducing house size is an effective way of reducing total energy consumption (Gray, 1998). One of the reasons for this regressive tendency is a physical phenomenon. Smaller houses have a higher proportion of envelope for a given volume, and therefore the fabric heat flux per unit of floor area or volume is greater in smaller houses. A study of project houses in NSW (SOLARCH, 2000) also found that double storey houses ordinarily could achieve acceptable scores (3.5 stars) with moderate levels of insulation, while single storey houses, especially smaller houses, could not easily achieve this rating. Yet according to one study (Luxmoore et al.,

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[9] Appliances in a home account for 35% of total energy use on average, and up to 50% in a moderate climate.

2005), the cooling requirements of larger houses with a high energy rating (5 stars or more) were found to be significantly higher than those of houses with a low (3.5) rating, which becomes particularly relevant in the context of predicted global warming (AGO, 2002).

It is most likely that an appropriate indicator for evaluating the efficiency of building design could address the issue of the performance of a building independent of artificial energy load. In that situation, an improvement in the thermal performance of a building should reduce the energy requirements for providing a thermally comfortable space. To fulfil the main objective of HERS, the indicator should be chosen so as to be *related* to the prediction of energy requirements, but not *exclusively based on* a prediction of energy requirements.

If a building is operated in the conditioned mode, the provision of thermal comfort is related to energy consumption. Occupants use energy for space heating or cooling when the indoor climate does not coincide with thermal comfort. However, where the indoor environment is naturally comfortable in terms of temperature and humidity, the need for an active energy load will decrease.

The question then arises as to whether thermal comfort can be used as a basis for assessing the efficiency of a house design. This is important for assessing the efficiency of a house in *entirely* free running operation mode, as opposed to assessing the efficiency of that house in conventional conditioned operation mode on the basis of energy usage.

The correlation between these two bases: comfort and energy, as indicators of the efficiency of a house in different operation modes is addressed in Chap. 4. A probabilistic correlation between thermal comfort and energy requirement does not necessarily mean that a house designed to be free running (comfort based) is an equally efficient conditioned house (energy based). This difference can be crucial with regard to the fundamental role of a house rating system which is intended to influence house performance improvement during the design of a house. This subject will be addressed in more detail in Chap. 4.

2.4.4 Occupancy Scenarios

Almost all reviewed rating systems designed to evaluate the thermal performance of buildings in terms of energy efficiency, set a standard scenario for occupants at the design stage to estimate the annual energy requirements of a building, and then evaluate the thermal performance of the building on the basis of that estimation. However, a standard set of behavioural assumptions for all possible occupancy scenarios cannot give an accurate evaluation.

Occupant behaviour is in fact the most significant determinant of actual energy use. One study suggests that 54% of the variation in energy consumption can be attributed to the building envelope and 46% to occupants' behaviour (Sonderegger, 1978). A similar study (Pettersen, 1994) concluded that where inhabitants' behaviour was unknown, the total predicted energy consumption resulted in +15 to 20% uncertainty, and the range of error for estimated energy heating use was +35 to 40% in a mild winter climate. A number of studies have gone further and shown that actual energy performance depends on the way the occupants "use" the buildings, and does not necessarily relate to the building design at all (Ballinger et al., 1991; Haberl et al., 1998). Indeed, "the predicted energy use or energy cost can be off by 50% or more due to occupant behaviour" (Stein and Meier, 2000).

In a standard occupancy scenario, the parameters such as the number of occupants, period of occupation and thermostat settings for air-conditioners are assumed to be standard. A standard occupancy scenario seems to be essential in order to simplify comparisons of building performance in similar conditions. However different occupancy scenarios can result in different grades or values for a building in a ranking system (Kordjamshidi et al., 2009). Some of the systems provide an option to set the actual number of occupants, but they cannot change the occupied time in a building when they are set for rating the building.

For instance AccuRate software, programmed for HERS in Australia, sets a standard scenario for "occupied time". Living zones are usually considered to be occupied for 17 h a day between 8 a.m. and midnight, and bed zones to be occupied for 17 h between 5 p.m. and 9 a.m. The "17 h scenario" is extremely effective in predicting the thermal performance of a house under a conservative possible occupancy regime, especially when taken together with a completely deterministic estimate of activation of artificial heating and cooling, regardless of occupants' behaviour or climatic seasons.

However, although the occupants' behaviour is not entirely predictable, a more realistic estimation could be employed to evaluate a building's performance and to estimate energy requirements for space heating and cooling. It is not generally possible to predict exactly at which times a dwelling is occupied, but defining multiple occupancy scenarios for rating could result in greater accuracy of prediction.

Setting a single time for occupation can particularly underestimate the value of lightweight buildings. In response to the current concerns about occupancy times and thermostat settings, Boland (2004) noted that "the lightweight dwelling may be disadvantaged unnecessarily". Depending on the time of occupation, a lightweight dwelling may give a better performance because it responds more quickly to temperature changes. This ability, in particular for short period occupation, and particularly in hot summers, is an advantage that cannot be addressed by a permanent "17 h occupancy scenario". The ability of lightweight buildings to achieve a favourable thermal performance needs therefore to be tested for different durations of occupied time.

Occupant behaviours are not a predictable factor. Szokolay (1992a) argues that occupancy factors cannot be taken into account in a rating system because of their high variability; so that the house itself has to be rated. In contrast, Olofsson et al. (2004) argue that if the rating is to reflect the energy efficiency of the occupied building, the actual influence of the users has to be taken into account, for which an evaluation of users is required.

2.4.5 Accuracy of HERS

The credibility of HERS depends on its accuracy. However several studies have demonstrated that the accuracy of energy based rating schemes is questionable. This situation is mainly due to the variability of occupancy behaviour and the rating index, as is described above. While the accuracy of rating systems has not been considered by HERS experts to be the most important barrier to widespread use of HERS, all agree that accuracy is important for the long-term credibility and success of this system. A lack of accuracy may eventually impact on some HERS and cause "irreparable" damage to credibility (Stein, 1997a; Stein and Meier, 2000).

It is clear that while HERS relies on an index of energy, the energy requirement cannot be estimated accurately. A comparison by Stein (1997a) between actual residential energy bills and energy estimation by four different HERS, namely CHEERS, HERO-Ohio, ERHC-Colorado and Midwest-Kansas, demonstrated a significant overestimation (50%) of actual energy cost by CHEERS, and smaller errors in estimating energy cost or energy use by the other methods. However, interestingly, no clear relationship was observed between rating scores and actual energy usage. Stein's case study investigation also showed that it is more difficult to accurately predict energy used in a mild climate than in a severe climate. Stein concluded that the main reason was the variation in occupants' behaviour, and suggested that "incorporating a few pieces of information" about occupants into a rating could improve its accuracy, while elsewhere he pointed out that "actual usage may vary" (Stein, 1997b).

A critical aspect of predicting energy consumption, and consequently of the accuracy of HERS, is determining thermostat settings. All of the current building rating systems consider standard defaults for thermostat settings, taken from thermally comfortable conditions in the building standards, based on a particular strategy. Employing an inappropriate strategy for thermostat settings can effectively reduce the accuracy of predicting energy requirements. This situation has been demonstrated to be more critical in a moderate climate, "where the balance between summer and winter energy consumption is a crucial factor and usually determines the nature of design advice" (Williamson and Riordan, 1997). Neglecting the effect of occupants' behaviour thus also appears to be an issue for thermostat settings in simulation methods for predicting the energy requirements of buildings.

Another issue is that occupants expect a higher degree of comfort in higher scoring buildings, and this tendency results in higher energy consumption than energy usage predicted by rating tools. The discrepancy occurs because the rating system depends on the active energy load, which is variable for different occupants. One way to deal with this problem could be to make house rating schemes independent of energy. Changing the basis of rating from energy to thermal comfort and evaluating buildings in free running mode could encourage the occupants to reduce the energy load for space heating and cooling, and to adapt themselves to natural conditions as far as possible.

2.4.5.1 The Accuracy of HERS Affected by Occupant Seasonal Behaviour

Ignoring seasonal occupant behaviours that respond to the psychological effect of cold and hot months also diminishes the accuracy of HERS. To predict the annual energy requirements in HERS, it is assumed that occupants use energy to maintain indoor temperature in the comfort range whenever the temperature is outside the comfort zone. However, in real life, reasonably, there is no tendency for occupants to mechanically heat a space during summer (hot months) even if the indoor temperature goes down for a few hours. Analogously, the opposite happens for over-heating periods during winter.

In a study by the author (Kordjamshidi et al., 2005b) it was shown that the simulation software correctly predicts that during summer the temperature may come down below the comfort range just between midnight to sunrise, and in winter it may rise above it around midday for just 2 or 3 h. These two particular conditions not only are not critical, but psychologically occupants may accept them as desirable. However, this fact has been ignored in the procedure of calculating or simulating annual energy demand in dwellings in most software developed for HERS, such as NatHERS.

2.5 Need for a New Index for Assessing Building Energy Efficiency

- Rating as ranking
  A rating system requires a simplified method of recognition of the complicated parameters of a building and its occupants. Although estimating energy requirements, particularly through simulation programs, seems a simplified method, this method depends on an active system design for dwellings. Any attempt to achieve an energy efficient design and to reduce energy consumption and GHG emissions relying only on the active energy load to evaluate a dwelling is not going to produce satisfactory results, since it encourages the public to acquire conditioned houses rather than efficient free running ones.

  A reliable rating system would be able to rank buildings in order of the efficiency of their design. This is recognised by Soebarto and Williamson (1999) who claim that "for a HERS mechanism to be sufficient for compliance testing it is only necessary that the scoring system be relatively correct" and by Stein (1997a, p. 17), who argues that "the actual numerical scores are not important as long as the houses are ranked in the correct order". On the other hand, as the above discussions show, it is realized that buildings which are designed for energy conservation in their free running performance cannot achieve a suitable score in the current rating systems. Therefore, when free running and conditioned buildings are ranked in the current rating systems, free running buildings are given inappropriate placement. This occurs when scoring is dependent on energy consumption ratings. There is, therefore, a need for a new index to be introduced, by which the thermal performance of buildings of any design type can be accurately scored and ranked.

To recapitulate, HERS have not been developed to predict the actual energy requirements of a house; the estimation of energy requirements is only a basis on which to make a comparison between the designs of houses for scoring them in relation to energy consumption. Where energy requirements cannot be predicted accurately, the scoring will not be a reliable reflection of the rate of efficiency of houses. If, on the other hand, the efficiency of a house design is to be evaluated on the basis of its free running performance, a new index would need to be proposed as the basis for a House Free running Rating Scheme (HFRS).[10] Where both types of performance of a house, conditioned and free running, are important at the policy level for the development of energy efficiency, then HERS and HFRS should be aggregated within one framework.

- Metrics, norms and diagnostics
  Three elements, namely *metrics*, *norms* and *diagnostics*, are used to evaluate the thermal performance of buildings. Metrics provides a quantification of the performance of the relevant components or systems, without indicating the quality of performance, while they form the basis for developing the norms against which components or system performance are compared. Diagnostics is a procedure involving measurements and analyses to evaluate performance metrics for a system or component under functional testing or actual building site conditions.

  Metrics used for the evaluation of the free running performance of buildings can be derived from the indexes of "thermal comfort". The next chapter reviews thermal comfort criteria to identify how they can be a reliable basis for a house rating scheme.

2.6 Summary

HERS are used to evaluate and promote efficient architectural building design. The most efficient buildings involve architecture design which can provide thermally comfortable indoor conditions for occupants without a mechanical thermal energy load. This means that the efficiency of a building design should be investigated in relation to the thermal performance of the building in free running operation. However, as described in this chapter, energy based ratings cannot at present deal with free running houses. The development of a House Free running Rating Scheme (HFRS), therefore, appears necessary in order to promote efficient architecture design and effectively reduce energy requirements in residential buildings.

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[10] House Free Running Rating Scheme (HFRS) is a clumsy term in English; however it has been used in this book to make it consistent with the previous term, "House Energy Rating Scheme (HERS)" for house ratings.

With regard to the shortcomings in the current rating schemes (see Sect. 2.4), the following aspects would need to be addressed to develop a reliable and accurate building rating scheme:

- Multiple occupancy scenarios, which should be added to the HERS. This would help to identify the likely better performance of lightweight houses.
- A new index on the basis of thermal comfort should be established as an indicator for evaluating the thermal performance of free running buildings, to form a basis for HFRS.
- The psychological effect of seasons on occupants in computing annual energy requirements should be considered. in order to increase the accuracy of energy based rating systems.
- Comparisons between the thermal performance of houses in conditioned and free running operation mode should be studied to see whether designs for free running houses differ from those for conditioned houses.
- A new framework should be developed for HFRS.
- Since large and double storey houses compared to single storey houses achieve better scores in current HERS, this comparison needs to be tested for free running houses.

These subjects will be addressed in the next chapters in this book, by considering typical residential houses and appropriate tools for evaluating the thermal performance of these houses in different operation modes.

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