CHAPTER 3

RESEARCH METHODOLOGY

3.0 Introduction

The aim of this chapter is to describe the test procedure for TV power measurement. The references the test procedure are adapted from and the suitability of the references are explained in this chapter. Besides that, this chapter discusses the methodology involved in the development and analysis of energy efficiency standard and label for TV sets in Malaysia. The methods for calculating energy, economical and environmental impacts of the standard and label are also discussed.

3.1 Energy test procedure

The key element in developing energy efficiency standard for TV sets in Malaysia is the establishment of a test procedure. A test procedure or protocol provides a method by which the efficiency or energy use of a product can be measured (Turiel *et al.*, 1997). The test procedure has at least two goals: correctly ranking models by efficiency and providing reasonably accurate estimates of actual home energy use (Turiel *et al.*, 1997).

A test procedure provides manufacturers, regulatory authorities and consumers a way of consistently evaluating energy use. An ideal test procedure should fulfill the following criteria (Meier and Hill, 1997):

- Reflect actual usage conditions
- Yield repeatable, accurate results
- Accurately reflect the relative performance of different design options for a given appliance
- Cover a wide range of models within that category of appliance
- Be inexpensive to perform
- Be easy to modify to accommodate new technologies or feature
- Produce results that can be easily compared with results from other test procedures

The goals are contradictory and a test procedure that tries to accurately duplicate actual usage will probably be expensive and not easily replicated (Meier and Hill, 1997). In this study it is intended a test procedure that reflects the actual TV usage conditions, yields repeatable and accurate results that can be easily compared with results from other test procedures is proposed. However the test procedure is a compromise between various types of TV available in the market such as the conventional CRT (Cathode Ray Tube) TV, plasma TV, LCD (Liquid Crystal Display) TV and Rear Projection TV.

Meanwhile Mahlia *et al.* (2002) stated that when developing a test procedure, adopting the ISO (International Organization for Standardization) test procedure is recommended. The reference explained that this approach would provide many advantages for a particular country such as reducing trade barriers, avoiding complicated technical procedure and saving time for developing test procedure especially to policy makers and manufacturers. This approach is not applicable in this study since the ISO standard does not cover TV power measurement. The test procedure used in this study is proposed using the references discussed in the next section.

3.2 Development of test procedure

Together with TV power measurement test procedure, it is necessary to define the equipment under test and other terminology related to TV power measurement. The definition of TV is adapted from IEC 60107-1 (1997) standard and Energy Star web site (2002). Both definitions give a brief description regarding TVs reliance to a display device and their function to receive broadcast or non-broadcast signals. The definitions for TV's active and standby mode on the other hand, are adapted from Wajer and Siderius (1998) and the definition of TV luminance level is adapted from IEC 60107-1 (1997) standard which explains in brief the term and unit involved.

The environmental conditions such as ambient temperature, humidity etc., that should be met during TV power measurement are adapted from MS 210 (1974) standard. This Malaysian Standard is not applicable for TV power measurement test procedure because it focuses on measurement of TV picture (also sound) quality, sensitivity and interference. The same environmental conditions apply for TV power measurement test procedure. It is important that the measurement of the TV power consumption shall be carried out at the rated voltage of the power supply. For this purpose IEC 60107-1 (1997) standard setting is used to determine the allowable fluctuation for power supply voltage, the allowable frequency fluctuation and the harmonic components of the power supply. The settings stated in this standard is also supported by prEN 50301 (1999) European standard proposal. MS 210 (1974) standard on the other hand, stated that nominal supply voltage fluctuation during measurement should be within ±10%. The range given by the Malaysian standard is found to be too wide especially for measurements in the standby mode, therefore will be omitted from the test proposal for TV power measurement.

Before conducting TV power measurement (in active or standby mode), it is necessary to allow the equipment to stabilize for a certain amount of time. For this purpose prEN 50301 (1999) standard proposal stated that the TV power consumption must be measured 15 minutes after it has been switched into relevant operating mode. In our study this condition will be adopted to ensure accuracy during measurement in this study. However the measurement procedures such as resolution need to be achieved and equipment set up are adapted from FEMP (United States Federal Energy Management Program) (2002) which gives a concise guide. Meanwhile, during measurement in active mode (or on mode) the luminance and audio level of the TV is set according to conditions stated in prEN 50301 (1999) standard proposal. The conditions stated in MS 210 (1974) standard is omitted because this standard was prepared in 1974 and TV technology especially display device had gone through a vast improvement ever since. However prEN 50301 (1999) standard proposal stated that if the luminance levels can not be adjusted, then the actual values shall be mentioned in the report. Moreover the standard explained that for non-CRT (Cathode Ray Tube) type of TV, a setting defined by the manufacturer shall be used and the setting shall be listed in the measuring report.

Another important aspect of TV power measurement is the measurement device. For this purpose, a measurement device (power meter) that enables average power consumption to be calculated is chosen. The measurement shall be repeated and the maximum permitted error for both measurements are set at 5%. Meanwhile, Energy Star (2002) suggested that a better measurement device will have higher crest factor specifications and more choices of current ranges for measurement in the standby mode. The crest factor is defined as the ratio of peak current (amps) to the RMS current (amps). They stated that measurement device with higher crest factor and more current range choices are capable of reading current drawn by the product (TV) without causing internal peak distortion (i.e., clipping off the top of the current). For this purpose, it is suggested that a power meter with a crest factor of 3 (or more) at a rated current range is used. Energy Star (2002) stated that to determine the crest factor rating requirement of the meter and the proper current range settings, the peak current (amps) draw of the product under test in standby mode must first be measured. Then a current range on the meter must be selected that is sufficient to register the peak current. Specifically, the full scale value of the current range selected multiplied by the crest factor of the meter (for current) must be greater than the peak current reading from the oscilloscope by at least 15 percent to compensate for any measurement error. Therefore, the usage of a power meter with crest factor of 3 seems satisfactory provided that the suitable current range is selected. Another important requirement of measurement device for TV measurement in the standby mode is the frequency response. The operating frequency range suggested by FEMP (2002) is used. This will ensure inaccuracies in power meter caused by harmonic waveforms can be avoided. On the other hand, power meter accuracy is also an important requirement for TV measurement. The power measurements (both in active and standby mode) shall be made with a meter capable of a tolerance of 1W (or less) preferably 0.1W for standby power as suggested by FEMP web site (2002) is recommended.

Finally all the results obtained and condition set during TV power measurement shall be recorded. The complete lists of information required in a test report are adapted from FEMP (2002). This reference gives a comprehensive list of information that shall be recorded. The developed test procedure is presented in Appendix C.

3.3 Equipment utilized

The equipment utilized for this study is the Yokogawa CW 140 Clamp-on power meter. The device (a portable unit) is used to measure various samples of TV sets in the standby mode covering Malaysian household in Kuala Lumpur and the state of Selangor. The general specifications are enumerated below.

- Frequency range – 45Hz to 1kHz (harmonics mode 45 – 66)
- Crest factor – 3 (for rated input)
- Display accuracy – Instantaneous value measurement function. Active power measurement accuracy 61 digit.
- Built in hard-drive to record continuos measurements

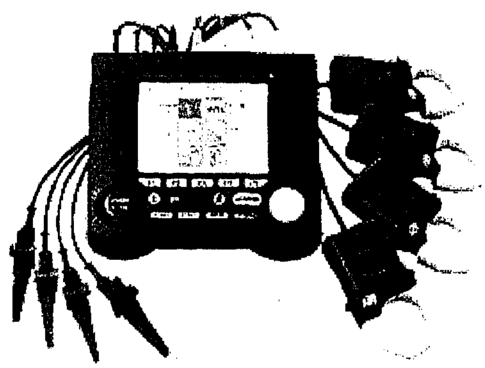

Figure 3.1 Yokogawa CW 140 Clamp-on power meter

Together with the clamp-on power meter, a professional multimeter is also utilized for TV power measurements. It is found that the clamp-on power meter performs inaccurate measurement of standby current especially on TV sets with low standby current. Therefore, the multimeter is utilized to verify and correct the reading. The general specifications are enumerated below.

- AC voltage: 4/40/400V60.8%, 700V61.2%
- AC current: 4/40/400mA61.5%, 10A63.0%

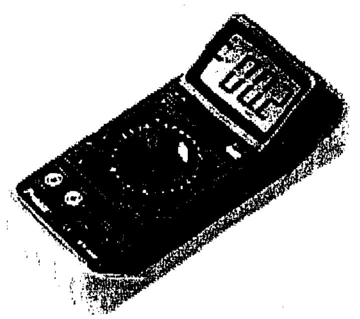

Figure 3.2 Pro's Kit 3PK-345 Professional multimeter

3.4 Energy efficiency standard

Energy efficiency standard or Minimum Energy Performance Standard (MEPS) is the specified minimum energy efficiency levels products must meet before they can be legally sold. These mandatory standards are set at levels which balance the technical possibility with economic viability and competitive forces within a particular market (Harrington and Damnics, 2002).

MEPS are usually not static but are revised over time to reflect improving levels of energy efficiency. MEPS rely on test procedures (often also called "Test Standards") which are used to determine appliance performance, energy consumption and hence energy efficiency. Harrington and Damnics (2002) stated that some countries prefer to encourage manufacturers to increase product efficiency in a voluntary manner without threat of regulation. According to the authors, instead of legislating MEPS, target efficiency levels are set usually based on average market efficiency rather than the performance of individual appliances and are referred to as targets or negotiated agreements.

Mahlia *et al.* (2002) pointed out that mandatory energy efficiency standard are generally the most effective way of rapidly improving the energy efficiency of appliances. The authors recommended that in order to avoid local manufacturer competing with technically proficient international manufacturer, developing countries could introduce standard efficiency improvement in several stages starting with low efficiency improvement and gradually increase to international level. Therefore, in this study the energy efficiency standard for TVs is implemented as a mandatory program based on the fact that mandatory program works effectively in many countries.

3.5 Development of energy efficiency standard

There are two approaches involved in setting energy efficiency standard. These are statistical approach and engineering/economic approach. The statistical approach requires data that are easier to obtain and involves less analysis compared to engineering/economic analysis. The data required for statistical approach are those that give a current characterization of the market place for the product of interests, namely the number of models by efficiency rating currently available for sale (Turiel *et al.* 1997).

Meanwhile engineering/economic approach is more sophisticated and data intensive approach. The engineering/economic approach seeks to determine the costs of efficiency improvements and the impacts on consumers through economic analysis, including life cycle cost and payback period calculations (Turiel *et al.* 1997). Nevertheless, according to Mahlia *et al.* (2002), whatever the approach in establishing efficiency standards, the following circumstances should be taken into consideration:

- The level of the standard must have a positive effect on the environment
- Before implementing the standard, the consumers should be protected against a high rise in total costs over the life of the given appliance
- The standard should guarantee energy efficiency and should not affect the quality of the appliance
- The standard should ensure market competitiveness

In this study, similar to the theory developed by Mahlia *et al.* (2002), we intend to use the statistical approach to set the standard for TVs, while the engineering/economic approach is used to analyze the potential efficiency improvement.

In order to carry out the statistical analysis, for each model of TV, its annual energy consumption (AEC) is plotted as a function of TV size (sizes are in inches). Next, a trend line is drawn through a regression analysis of all the data points. This is the average energy use baseline (as of 2003). To predict the average energy use baseline as of 2005[1] however, the following equation is utilized.

$$AEC_{STD} = AEC_{SC} \times (1 - AEI)^{(Ypd - Ysc)} \qquad (3.1)$$

where

AEC_{SC}	=	Annual energy consumption on the year survey conducted	(kWh)
AEC_{STD}	=	Annual energy consumption on the year standard is proposed	(kWh)
AEI	=	Annual efficiency improvement	(%)
Ypd	=	Year standard is proposed	
Ysc	=	Year survey is conducted	

[1] Year energy standard is proposed

Together with the average energy use baseline, a 10% energy saving line is drawn. The 10% energy saving line represents the standard that is proposed in this study. This standard level was chosen because, before the annual efficiency improvement of TV sets which is 2% (as shown in Chapter 4, Section 4.5) starts to catch up with the standard, it allows huge positive impact to occur in this country and gives policy makers ample time to revise the standard. As a result of the 10% energy saving line, any TV unit with energy use above this line is regarded as inefficient or incompliant with the standard. It is replaced with a model of higher efficiency so that the number of model stays constant (Turiel *et al.*, 1997). The method used to obtain the 10% line is by replacing the TVs (that drew the average energy baseline) with a fictitious unit of similar size but consuming 10% less energy.

Meanwhile to conduct engineering/economic analysis, Turiel *et al.* (1997), suggested the following steps that should taken into consideration:

- Select appliance classes
- Select baseline units
- Select design options for each classes
- Calculate efficiency improvement from each design option
- Combine design options and calculate efficiency improvements
- Develop cost estimates (include installation and maintenance) for each design option
- Generate cost-efficiency curves

The purpose of the engineering/economic analysis in this study is to examine whether the proposed 10% standard is achievable or not by analyzing the TV sets potential efficiency improvement. To implement the standard program, the standard level must be achievable with an acceptable cost impact. To conduct the engineering/economic analysis for our study, firstly TVs are divided into 4 classes according to its types of display device being utilized, which are conventional CRT (Cathode Ray Tube) TV, LCD (Liquid Crystal Display) TV, Plasma TV and Rear Projection TV. The selection of product classes made for this study are in line with the suggestions made by Turiel *et al.* (1997) that stated classes are differentiated by capacity or performance that affect efficiency and provide utility to the consumers. Basically a plasma TV, which comes in a space saving flat screen format and in a screen size of above 32-inch, consumes more electricity than any other types of TV. An average 50-inch plasma TV for example, consumes more electricity than an average 50-inch projection TV. CRT and LCD TVs on the other hand are currently not available yet in the 50-inch category. This makes them on average more efficient than plasma and projection TV technology. However the difference between CRT and LCD TVs are the latter comes in a flat screen format.

The next step for conducting engineering/economic analysis is the selection of baseline unit. For this purpose, the least efficient TV model from each product class is chosen. This method of selection is also recommended by Turiel *et al.* (1997) because it permits analysis of trial standard at all possible levels of efficiency starting from eliminating the least efficient model. After this step, the design options that improves TV efficiency for each product class need to be selected. For this purpose, it is intended to improve the (main) switched-mode power supply component, introduce 1-W standby power technology and also other design options. For each design option, energy use or efficiency is determined. The expected costs of manufacturing each design option are also determined. For this purpose, the appropriate manufacturers were contacted to obtain the price list. However Turiel *et al.* (1997) stated that manufacturing costs are sometimes very difficult to obtain and it may be necessary to go directly to retail cost. Therefore in this study, retail cost as well as estimations from a third party such as researches will serve as the alternative in the absence of manufacturing costs.

Meanwhile, it should be noted that the installation and maintenance costs are excluded from the cost estimate calculation for design options that are replacements of older devices. This is because the installation and maintenance costs of the new design option are assumed to be the same as the inefficient device.

Finally, using the manufacturing cost and energy use values, a cost-efficiency curve is generated. For this purpose, the following three methods could be utilized:

- Life cycle cost calculation method
- Simple payback period calculation method
- Payback period calculation method

In order to carry out these analyses, the following assumptions are made:

- Operating expenses of the TV is constant over life time
- Discount rate is constant over life time
- Usage pattern (e.g. standby hours) is constant over life time

3.5.1 Life cycle cost calculation method

The life cycle cost (LCC) is calculated in the year standard is imposed using a discount rate (r) to determine the present value of the future energy cost savings. The discount rate used in this study is 7%. Turiel *et al.* (1997) defined life cycle cost (LCC) as the sum of the purchase price (PP) and the annual operating expense (OE) discounted over the life span (L) of a particular appliance. Generally the life cycle cost of an appliance consists could be expressed as the following equation:

$$LCC = PP + \sum_{1}^{L} \frac{OE_t}{(1+r)^t} \tag{3.2}$$

In this study the operating expenses are assumed to be constant over time. Hence the above equation reduces to:

$$LCC_{option} = PP_{option} + PWF \times OE_{option} \tag{3.3}$$

where

LCC_{option}	=	Life cycle costs of TV with design option	(\$)
PP_{option}	=	Purchase price of TV with design option	(\$)
PWF	=	Present worth factor	
OE_{option}	=	Operating expenses per year of TV with design option (energy costs)	(\$/year)

Meanwhile, the present worth factor can be calculated as follows:

$$PWF = \frac{1}{r}\left[1 - \frac{1}{(1+r)^L}\right] \quad (3.4)$$

where

PWF	=	Present worth factor	
r	=	Discount rate	(%)
L	=	Life span of TV	(year)

3.5.2 Simple payback period calculation method

Wajer and Siderius (1998) defined the simple payback period (SPP) as the extra initial costs (purchasing price) to the consumer divided by the annual savings in operating expenses. The authors stated that the SPP is useful as a first indication of the relative economic feasibility of the design options. However for the cost-efficiency analysis in this study, the simple payback period calculation is omitted in order to concentrate on the payback period calculation. The SPP can be calculated as follows (Wajer and Siderius, 1998):

$$SPP_{option} = \frac{\Delta PP_{option}}{-\Delta OE_{option}} \quad (3.5)$$

where

SPP_{option}	=	Simple payback period of design option	(year)
ΔPP_{option}	=	$PP_{option} - PP_{baseline}$	($)
ΔOE_{option}	=	$OE_{option} - OE_{baseline}$	($/year)

3.5.3 Payback period calculation method

Meanwhile Wajer and Siderius (1998) defined the payback period (PBP) as the time taken to recover the additional investment as a result of lower operating costs. The authors explained that as long as the payback period is shorter than the life span of the appliance, the design option is economically feasible. PBP is defined as the difference between the natural logarithm of operating expenses and purchase price ratio with and without the presence of discount rate divided by the natural logarithm of one plus the discount rate. The PBP could be expressed as the following equation (Wajer and Siderius, 1998):

$$PBP_{option} = \frac{\ln\left(\frac{-\Delta OE_{option}}{\Delta PP_{option}}\right) - \ln\left(\frac{-\Delta OE_{option}}{\Delta PP_{option}} - r\right)}{\ln(1+r)} \qquad (3.6)$$

where

PBP_{option}	=	Payback period of design option	(year)
r	=	Discount rate	(%)
ΔPP_{option}	=	$PP_{option} - PP_{baseline}$	($)
ΔOE_{option}	=	$OE_{option} - OE_{baseline}$	($/year)

3.6 Data collection method

There are two methods used for collecting data. The first method involves conducting a survey by distributing questionnaires to consumers throughout the country. For this purpose, 275 questionnaires were distributed to Malaysian household in 11 states covering Peninsular and East Malaysia. The data collected from this method include the type of TV being used, year TV manufactured, average TV usage pattern, number of units and other related information. However, the main purpose for conducting the survey is to estimate the average TV usage hours. This figure will serve as the basis to compute the annual energy consumption.

The second method involves conducting power measurement test. For this purpose, 20 TVs of different brand and size were metered in the standby mode. The metering was conducted according to the developed test procedure. During this period, the TV active mode data provided by the manufacturer (can be read from the adhesive label in the rear position of TV) are also collected. The rest of nearly 500 TVs active mode and standby mode data have been compiled from manufacturer's TV catalogue, market survey conducted at electrical retail shops and data published by organizations such as Energy Star (2002) and GEEA (Group for Efficient Appliances, 2001). All the collected data are presented in Appendix B and the analysis of the data are shown in Chapter 4.

3.7 Impact of energy efficiency standard

In the following section the method to predict data and calculate energy, economical and environmental impact of the standard are presented. These methods are adapted from the theory developed by Mahlia *et al.* (2002).

3.7.1 Predicted data

It is understood that the standard will be established sometime after the data is collected. Therefore, the data must be predicted in order to get the distribution data for future use. The distribution of the future data is predicted using the polynomial curve fitting method. In our study, this method is used to estimate the residential TV ownership data. Besides that, the fuel mix of electricity generation in Malaysia is also predicted using this method. The results of the predicted data are presented in Chapter 4. Mathematically, a polynomial of order k in x is expressed in the following form:

$$y = c_0 + c_1 x + c_2 x^2 + \ldots + c_k x^k \qquad (3.7)$$

where

c,k	=	Constant value
y	=	Predicted value
x	=	Year predicted – year start

3.7.2 Energy impact of the standard

The energy impact of TV standard is calculated based on the average annual energy use in the Malaysian household and the annual energy use in the presence of standard. To calculate the energy impact of the standard, some essential calculations were made. These include TV shipment which was calculated using the TV ownership data (obtained from the Department of Statistics), the number of TVs affected by the standard, scaling factor, energy savings and business as usual (energy consumption in the absence of standard) calculation. A comprehensive description of each variable calculated is explained in the following section.

3.7.2.1 Shipment

Shipment data comprises the number of TVs in the predicting year minus the number of TVs in the previous year plus the number of retired TVs in the current year. However, Population and Housing Census of Malaysia (1970, 1980, 1991& 2000) only provided us with the number of households with TV data. Therefore, the TV saturation level per household is taken into consideration. The mathematical expression can be written as:

$$Sh_i = ((Na_i - Na_{i-1}) + Na_{i-L}) \times S_i \qquad (3.8)$$

where

L = Life span of TV (year)

Na_i	=	Number of households with TV in year i
Na_{i-1}	=	Number of households with TVs in year i-1
Na_{i-L}	=	Number of households with TVs in year i-L
S_i	=	TV saturation level per household in year i
Sh_i	=	Shipments of TV in year i

3.7.2.2 Baseline energy consumption

The baseline energy consumption is multiplication of the energy consumption and the usage hours (in one year) of the TV during active mode, plus the multiplication of standby energy consumption and standby hours of the TV, in the year standard is enacted. The baseline energy consumption can be expressed as the following equation:

$$BEC_s = \frac{(E_0 \times U_0) + (E_t \times U_t)}{1000} \qquad (3.9)$$

where

BEC_s	=	Baseline energy consumption for TV	(kWh/yr)
E_0	=	Energy consumption of TV in on mode	(Watts)
E_t	=	Energy consumption of TV in standby mode	(Watts)
U_0	=	Usage hours of TV in on mode	(Hours/yr)
U_t	=	Usage hours of TV in standby mode	(Hours/yr)

3.7.2.3 Standard energy consumption

The standard energy consumption is a function similar to the baseline energy consumption. However the function is multiplied by one minus the proposed standard to compute the energy consumption after the standard have been enacted. The standard energy consumption can be expressed as:

$$SEC_s = (1 - STN) \times \left(\frac{(E_0 \times U_0) + (E_t \times U_t)}{1000} \right) \quad (3.10)$$

where

E_0	=	Energy consumption of TV in on mode	(Watts)
E_t	=	Energy consumption of TV in standby mode	(Watts)
SEC_s	=	Standard energy consumption of TV	(kWh/yr)
STN	=	Proposed standard	(%)
U_0	=	Usage hours of TV in on mode	(Hours/yr)
U_t	=	Usage hours of TV in standby mode	(Hours/yr)

3.7.2.4 Initial unit energy savings

The initial unit energy savings is the difference between the annual unit energy consumption of a average TV unit meeting the standard and the unit energy consumption of a average unit that would have been shipped in the absence of standard. The actual unit energy consumption for a particular TV depends on its display device and screen size. The initial unit energy savings can be expressed as:

$$UES_s = BEC_s - SEC_s \qquad (3.11)$$

where

BEC_s	=	Baseline energy consumption for TV	(kWh/yr)
SEC_s	=	Standards energy consumption for TV	(kWh/yr)
UES_s	=	Initial unit energy savings in year i for TV	(kWh/yr)

3.7.2.5 Scaling factor

The scaling factor would linearly scale down the unit energy savings of the TV over the effective lifetime of the standard. This is because TV technology gradually improves. The trend over time may decrease energy consumption with or without the presence of standard. Scaling factor can be expressed in a mathematical form as:

$$SF_i = 1-(Ysh_i - Yse_s)\ \frac{AEI_s}{SEI_s} \tag{3.12}$$

where

AEI_s	=	Annual energy efficiency improvement for TV	(%)
SEI_s	=	Standard energy efficiency improvement for TV	(%)
SF_i	=	Scaling factor in year i for TV	(%)
Ysh_i	=	Year i of shipment of TV	
Yse_s	=	Year of standard enacted of TV	

3.7.2.6 Shipment Survival Factor

Shipment survival factor is a function of annual retirement rate and retirement function. It can be calculated by the following equation:

$$SSF_i = 1 - \left[\frac{(Ysc - Ysh_i) - \frac{2}{3}\ L}{(\frac{4}{3} - \frac{2}{3})\ L}\right] \tag{3.13}$$

where

L	=	Life span of TV
SSF_i	=	Shipment survival factor in year i for TV
Ysh_i	=	Shipment of TV in year i
Ysc	=	Year saving calculation for TV

3.7.2.7 Unit energy savings

The unit energy savings have to be adjusted starting from year standard is enacted till the effective lifetime of the standard using the efficiency trend scaling factor. This factor corresponds to the natural progress in more efficient TV. The unit energy saving can be expressed in mathematical form as follows:

$$UES_i = SF_i \times UES_s \tag{3.14}$$

where

SF_i	=	Scaling factor in year i for TV	(%)
UES_i	=	Unit energy savings in year i for TV	(kWh/yr)
UES_s	=	Initial unit energy savings in year i for TV	(kWh/yr)

3.7.2.8 Applicable stock

The applicable stock is the shipment of TV in a particular year plus the number of TV affected by the standard in the previous year. The applicable stock can be expressed in mathematical form as:

$$AS_i = (Sh_i \times SSF_i) + AS_{i-1} \tag{3.15}$$

where

AS_i = Applicable stock of TV in year i

AS_{i-1}	=	Applicable stock of TV in year i-1	
Sh_i	=	Shipments of TV in year i	
SSF_i	=	Shipment survival factor in year i for TV	

3.7.2.9 Annual energy savings

The initial unit energy saving in a particular year is multiplied by the scaling factor for that particular year to determine the unit energy savings for TVs purchased in that year. The unit energy saving is then multiplied by the number of applicable stock to calculate the annual energy savings. The mathematical expression can be written as:

$$ES_i = AS_i \times UES_i \times SF_i \qquad (3.16)$$

where

AS_i	=	Applicable stock of in year i of TV	
ES_i	=	Energy saving in year i for TV	(kWh/yr)
SF_i	=	Scaling factor in year i for TV	(%)
UES_i	=	Unit energy savings in year i for TV	(kWh/yr)

3.7.2.10 Business as usual

Business as usual is the energy consumption of the TV sets in the absence of standard. Business as usual can be expressed in mathematical form as:

$$BAU_i = AS_i \times BEC_s \times IE_i \quad (3.17)$$

where

AS_i	=	Applicable stock of in year i of TV	(year)
BAU_i	=	Business as usual energy consumption in year i for TV	(kWh/yr)
BEC_s	=	Baseline energy consumption for TV	(kWh/yr)
IE_i	=	Energy efficiency improvement in year i for TV	(%)

3.7.2.11 Standard energy consumption

Standard energy consumption is the difference between energy consumption of TVs in the absence of standard with the annual energy savings. Standard energy consumption can be written as:

$$STD_i = BAU_i - ES_i \quad (3.18)$$

where

BAU_i	=	Business as usual energy consumption in year i for TV	(kWh/yr)
ES_i	=	Energy saving in year i for TV	(kWh/h)

STD_i	=	Energy consumption with standard in year i for TV	(kWh/h)

3.7.3 Economic impact of the standard

The economic impact consists of the potential bill savings, net savings, and cumulative present value. The economic impact is actually a function of the energy savings and investment for more efficient appliances due to the standard. The comprehensive description of each variable is explained in the following sections.

3.7.3.1 Initial incremental cost

The initial incremental cost per unit TV is a function of the unit energy savings and incremental cost. It can be calculated using the following equation:

$$IIC_s = UES_s \times IC \tag{3.19}$$

where

IC	=	Incremental cost of TV	(\$/kWh)
IIC_s	=	Initial incremental cost of more efficient TV	(\$/unit)
UES_s	=	Initial unit energy savings in year i for TV	(kWh/yr)

3.7.3.2 Capital recovery factor

The capital recovery factor is the correlation between the real discount rate and the life span of TV. This correlation can be expressed by the following mathematical equation:

$$CRF = \frac{d}{(1-(1+d)^{-L})} \tag{3.20}$$

where

CRF	=	Capital recovery factor	(%)
d	=	Interest rate per year	(%)
L	=	Life span of TV	(year)

3.7.3.3 Cost conserved energy

The cost of conserved energy due to the standard is a function of the initial incremental cost and capital recovery factor, divided by the initial unit energy savings. Mathematically it can be expressed by the following equation:

$$CCE_s = \frac{IIC_s \times CRF}{UES_s} \tag{3.21}$$

where

CCE_s	=	Cost of conserved energy for TV	($/kWh)

CRF	=	Capital recovery factor	(%)
IIC_s	=	Initial incremental cost of more efficient TV	($/unit)
UES_s	=	Initial unit energy savings in year i for TV	(kWh/yr)

3.7.3.4 Bill Savings

The bill saving is a function of energy savings multiplied by average fuel price and is expressed in the following equation:

$$BS_i = ES_i \times PF_i^n \qquad (3.22)$$

where

BS_i	=	Bill savings in year i for TV	($)
ES_i	=	Energy saving in year i for TV	(kWh/yr)
PF_i^n	=	Fuel price in year i for fuel type n	($)

3.7.3.5 Net savings

There are two methods available to estimate economic impact, which are annualized costs and cash flow. In the first method, the incremental cost is spread over the life span of the appliance so that the pattern of expenditures matches the flow of bill savings. This method smoothes net savings over the time. The annualized net dollar savings in a particular year, which is the main economic indicator used in this analysis, is calculated using the following equation:

$$ANS_i = (ES_i \times PF_i^n) - (AS_i \times CRF \times SF_i \times IIC_s) \qquad (3.23)$$

where

ANS_i	=	Annualized net dollar savings in year i for TV	(\$)
AS_i	=	Applicable stock of in year i of TV	
CRF	=	The capital recovery factor	(%)
ES_i	=	Energy saving in year i for TV	(kWh/yr)
IIC_s	=	Initial increment cost of the more efficient TV	(\$/unit)
PF_i^n	=	Fuel price in year i for fuel type n	(\$)
SF_i	=	Scaling factor in year i for TV	(%)

The second method considers the cash flow over the lifetime of the investment, assuming that the appliance is paid in full amount when it is bought. Purchasers incur the incremental cost when the appliance is purchased, but the benefits of higher energy efficiency are spread over the life span of the appliance. The net saving in the year i in term of actual cash flows, is calculated using the following equation:

$$NS_i = (ES_i \times PF_i^n) - (Sh_i \times SF_i \times IIC_s) \qquad (3.24)$$

where

ES_i	=	Energy saving in year i for TV	(kWh/yr)
IIC_s	=	Initial incremental cost of more efficient TV	(\$/unit)
NS_i	=	*Net saving in year i for TV*	(\$)

PF_i^n	=	Fuel price in year i for fuel type n	(\$)
SF_i	=	Scaling factor in year i for TV	(%)
Sh_i	=	Shipments in year i for TV	

3.7.3.6 Cumulative present value

The cumulative present value of annualized net savings can be calculated using a percentage real discount rate and can be expressed in a mathematical form by the following equation:

$$PV(ANS_i) = \frac{ANS_i}{(1+d)^{(i-Ydr)}} \tag{3.25}$$

where

ANS_i	=	Annualized net dollar savings in year i for TV	(\$)
d	=	Interest rate per year	(%)
$PV(ANS_i)$	=	Present value of annualized net saving in year i for TV	(\$)
Ydr	=	Year of discount rate base	

3.7.4 Environmental impact of the standards

Power generation from fossil fuel causes hazardous emissions. As a result of the energy savings that occur from TV standard, it is possible to mitigate a certain portion of hazardous emissions. In this study, environmental impact of the standard is the potential reduction of greenhouse gases and other gases that cause negative impacts to the environment

3.7.4.1 Emission reduction

The common emissions from fossil fuel power generation consist of CO_2, SO_2, NO_x *and CO. The emission reduction is a function of energy savings.* The emissions reduction from the standard implementation can be calculated using the following equation:

$$ER_i = ES_i(PE_i^1 \times Em_p^1 + PE_i^2 \times Em_p^2 + \cdots + PE_i^n \times Em_p^n) \qquad (3.25)$$

where

ES_i	=	Energy saving in year i for TV	(year)
Em_p^n	=	Emission p for fuel type n for unit electricity generation	(kg/kWh)
ER_i	=	Emission reduction in year i of TV	(kg)
PE_i^n	=	Percentage of electricity in year i for fuel type n	(%)

3.8 Energy Label

Mahlia *et al.* (2001) defined energy label as a mandatory or voluntary sticker that is affixed to products or their packaging containing information on the energy efficiency or energy consumption of the product. Basically, an energy label works in three main ways (Wiel & McMahon, 2001);

- It provides consumers with data on which to base informed choices (to select the most efficient and suitable product available)
- It encourages manufacturers to improve the energy performance of their models
- It encourages distributors and retailers to stock and display efficient products

The first evaluation on the EU (European Union) labeling scheme for refrigeration appliances show that the sales-weighted average energy efficiency improved by 29% between 1992 and late 1999 (Wiel & McMahon, 2001). It is estimated that 16% of the impact is due to minimum efficiency standards and 10% is due to the impact of labeling (Wiel & McMahon, 2001).

Besides that, as a general rule of thumb, energy labeling will work best for products that correspond to these criteria (Wiel & McMahon, 2001);

- use a significant amount of energy
- are present in most households (or where rapid growth is predicted)
- for which energy-efficient technology exists that is not being used in most products on the market,
- for which the purchaser pays the energy bills

- for which there is (or could easily be) significant variation in the energy efficiency of different units

Based on these criteria, it seems sensible to propose an energy label program for TV sets in Malaysia. This is due to the fact that TV sets uses significant amount of energy especially technology such plasma TV. Moreover it is present in most households and the ownership of more than one TV sets per household are also increasing. Besides that, technologies such as for improving the standby power to 1-Watt have not been utilized in most TV sets sold in Malaysia. Therefore this study is in the right track in proposing energy label program for TV sets in Malaysia.

3.8.1 Legal status

Similar to energy efficiency standard, the legal status of energy label program could also be implemented mandatory or voluntary. The mandatory program requires manufacturers to affix all TV sets with energy label when being sold in the market. The voluntary label on the other hand, is an optional approach whereby manufacturers may or may not affix the energy label. However according to Mahlia (2002), voluntary label does not work well in many countries. This is due to the fact that certain manufacturers may opt not to display energy label on their product. Furthermore, consumers will face difficulties in choosing the most efficient appliance with the most competitive price. Therefore, a mandatory label seems to be a wise choice.

3.9 Energy label development

The energy label design used for this study is adapted from the draft of Malaysian Standard of Energy labeling for electric fan in Malaysia (TCPHEA, 2002). The label ranks the devices according to number of stars whereby 5 star rating being the most the efficient device. By adapting this label design, a consistent label style and format across appliance type could be achieved, which is an important criteria for developing an energy label (Wiel & McMahon, 2001).

3.9.1 Star rating calculation

As result of the energy label being ranked according to the number of stars, it is necessary to calculate the star rating. In this study an indicator referred to as the incremental step size (δ) is used to compute the star rating. The incremental step size (δ) is defined as below. The equation is adapted from TCPHEA (2002).

$$\delta = \frac{AEC_{i_{AVG}} - AEC_{i_{MIN}}}{3} \qquad (3.26)$$

where

$AEC_{i_{AVG}}$	=	Average annual energy consumption	(kWh)
$AEC_{i_{MIN}}$	=	Minimum annual energy consumption	(kWh)
δ	=	Incremental step size	

Meanwhile, the energy label adapted from TCPHEA (2002) also displays the energy consumption of appliance in kilowatt-hours per year. Therefore in this study, the annual energy consumption (AEC) data compiled from the statistical analysis could be transferred straight to calculate the star rating. Table 3.1 shows the star rating calculation method that will be used for this study. If as a matter of fact a different indicator besides AEC need to be displayed, then the change would be as simple as replacing the AEC expression in equation (3.26) and Table 3.1 with the new expression. In fact for this study, it is intended that an energy efficiency index (E_i) be displayed as the indicator to replace AEC. However the status of this intention could only be determined after the statistical analysis is completed in chapter 4. The mathematical expression for energy efficiency index is presented in equation (3.27).

Table 3.1 Star rating calculation

Star Rating	Energy Efficiency Index
1 Star	Maximum AEC - δ≤ AEC ≤ Maximum AEC
2 Stars	Minimum Value of 1 Star - δ≤ AEC 'Minimum Value of 1 Star
3 Stars	Minimum Value of 2 Star - δ≤ AEC ' Minimum Value of 2 Star
4 Stars	Minimum Value of 3 Star - δ≤ AEC ' Minimum Value of 3 Star
5 Stars	AEC' Minimum Value of 4 Star

$$E_i = \frac{AEC}{E_R} \times 100 \qquad (3.27)$$

where

AEC	=	Annual energy consumption of TV set	(kWh/yr)
E_i	=	Energy efficiency index	
E_R	=	Reference energy consumption	(kWh/yr)

3.10 Impact of energy label

The method to calculate the impact of energy label is adapted from the theory developed by Mahlia *et al.* (2002). In this study, the impact of energy label is calculated based on three scenarios (SC), which are the central values of each label rating. The scenarios are minimum expected (SC-1), nominal expected (SC-2) and maximum expected (SC-3), which corresponds to label ratings of 1 star, 3 stars and 5 stars each respectively.

3.10.1 Energy impact of label

3.10.1.1 Baseline energy consumption

The baseline energy consumption for energy label is the standard energy consumption. This is because energy label program is intended to be implemented simultaneously with the energy standard program in this study.

3.10.1.2 Labels energy consumption

In this study, the impact of energy label is calculated based on three scenarios which corresponds to 1-star, 3-star and 5-star rating. As a result the label energy consumption is the central value of AEC from the 1-star, 3-star and 5-star rating. The label energy consumption can be expressed as follows:

$$LEC_l = AEC_{SC} \tag{3.28}$$

where

AEC_{SC}	=	Annual energy consumption for TV from three selected scenarios	(kWh/yr)
LEC_l	=	Label energy consumption for TV	(kWh/yr)

3.10.1.3 Unit energy savings

The unit energy saving is the difference between the baseline energy consumption of label and the label energy consumption. Thus, the label unit energy savings is:

$$UES_l = SEC_l - LEC_l \tag{3.29}$$

where

LEC_l	=	Label energy consumption for TV	(kWh/yr)

SEC_l	=	Standards energy consumption for TV	(kWh/yr)
UES_l	=	Unit energy savings from label implementation	(kWh/yr)

3.10.1.4 Shipment survival factor

The shipment survival factor is a function of the annual retirement rate and the retirement function, which can be calculated using the following function:

$$SSF_i = 1 - \left[\frac{(Ysc - Ysh_i) - \frac{2}{3} L}{(\frac{4}{3} - \frac{2}{3}) L} \right] \tag{3.30}$$

where

L	=	Life span of TV
SSF_i	=	Shipment survival factor in year i for TV
Ysh_i	=	Shipment of TV in year i
Ysc	=	Year saving calculation for TV

3.10.1.5 Applicable stock

The applicable stock is the shipment in a particular year multiplied by the shipment survival factor plus the number of appliances affected by labels in the previous year. The mathematical equation can be expressed as:

$$AS_i = (Sh_i \times SSF_i) + AS_{i-1} \tag{3.31}$$

where

AS_i	=	Applicable stock of TV in year i	
AS_{i-1}	=	Applicable stock of TV in year i-1	
Sh_i	=	Shipments of TV in year i	
SSF_i	=	Shipment survival factor in year i for TV	

3.10.1.6 Annual energy savings

The annual energy savings is the number of appliances affected by the label in the particular year, that still exist, multiplied by the unit energy savings associated with label grade for each scenario. Since the standard is static, there is no scaling used in calculating the energy savings of label. In the mathematical expression, it can be written as follows:

$$ES_i = AS_i \times UES_l \qquad (3.32)$$

where

AS_i	=	Applicable stock of in year i of TV	
ES_i	=	Energy saving in year i for TV	(kWh/yr)
UES_l	=	Unit energy savings from label implementation	(kWh/yr)

3.10.1.7 Business as usual

Since the labels are developed as a pair with the standards, the business as usual for calculating the label energy consumption is the standard's energy consumption of the appliance.

3.10.2 Economic impact of the label

The economic impact of the label consists of the potential bill savings, net savings and cumulative present value. The economic impact is a function of the energy savings and the investment for more efficient appliance due to the label. The comprehensive description of each variable is explained in the following sections.

3.10.2.1 Initial incremental cost

The initial incremental cost per unit of appliance is a function of the unit energy savings and the incremental cost. It can be calculated using the following equation:

$$\mathrm{IIC}_l = \mathrm{UES}_l \times \mathrm{IC} \qquad (3.33)$$

where

IC = Incremental cost of TV ($/kWh)

IIC_l	=	Initial incremental cost of more efficient TV	(\$/unit)
UES_l	=	Unit energy savings from label implementation	(kWh/yr)

3.10.2.2 Capital recovery factor

The capital recovery factor is the correlation between the real discount rate and the life span of the appliance. This correlation has been expressed in equation (3.20).

3.10.2.3 Cost conserved energy

The cost of conserved energy due to label is a function of the initial incremental cost and capital recovery factor, divided by the unit energy savings. Mathematically it can be expressed by the following equation:

$$CCE_l = \frac{IIC_l \times CRF}{UES_l} \qquad (3.34)$$

where

CCE_l	=	Cost of conserved energy for TV	(\$/kWh)
CRF	=	Capital recovery factor	(%)
IIC_l	=	Initial incremental cost of more efficient TV	(\$/unit)
UES_l	=	Unit energy savings from label implementation	(kWh/yr)

3.10.2.4 Net savings

Similar with the standard, for energy label there is also two methods to estimate economic impact, which are annualized costs and cash flow. In the first method, the incremental cost is spread over the lifetime of the appliance so that the pattern of expenditure matches the flow of bill savings. This method smoothens the net savings over time. Since the standard energy consumption is static, no scaling factors are used to calculate the label savings. The annualized net dollar savings in a particular year, which is the main economic indicator, is calculated using the following equation:

$$ANS_i = (ES_i \times PF_i^n) - (AS_i \times CRF \times IIC_l) \quad (3.35)$$

where

ANS_i	=	Annualized net dollar savings in year i for TV	($)
AS_i	=	Applicable stock of in year i of TV	
CRF	=	The capital recovery factor	(%)
ES_i	=	Energy saving in year i for TV	(kWh/yr)
IIC_l	=	Initial increment cost of the more efficient TV	($/unit)
PF_i^n	=	Fuel price in year i for fuel type n	($)

The second method considers the cash flow over the lifetime of the investment assuming that the appliance is paid for in full when it is bought. Purchasers incur the incremental cost when the appliance is purchased, but the benefits of higher energy efficiency are spreading over lifetime of the appliance. To calculate the net savings in a certain year in terms of actual cash flows, the following equation can be used:

$$NS_i = (ES_i \times PF_i^n) - (Sh_i \times IIC_l) \qquad (3.36)$$

where

ES_i	=	Energy saving in year i for TV	(kWh/yr)
IIC_l	=	Initial incremental cost of more efficient TV	($/unit)
NS_i	=	Net saving in year i for TV	($)
PF_i^n	=	Fuel price in year i for fuel type n	($)
Sh_i	=	Shipments in year i for TV	

3.10.2.5 Cumulative present value

The cumulative present value can be calculated using the percentage of real discount rate. The cumulative present value of the annualized net savings can be expressed in a mathematical form as follows:

$$PV(ANS_i) = \frac{ANS_i}{(1+d)^{(i-Ydr)}} \qquad (3.37)$$

where

ANS_i	=	Annualized net dollar savings in year i for TV	($)

d	=	Interest rate per year	(%)
$PV(ANS_i)$	=	Present value of annualized net saving in year i for TV	($)
Ydr	=	Year of discount rate base	

3.10.3 Environmental impact of the label

The environmental impact from fossil fuel energy sources consists of the carbon dioxide, sulfur dioxide, nitrogen oxide and carbon monoxide emissions reduction. The environmental impact is also a function of the energy savings. The impact is a benefit to the society from choosing more efficient appliances due to the label program. The environmental impact of label is calculated by the following equation:

$$ER_i = ES_i(PE_i^1 \times Em_p^1 + PE_i^2 \times Em_p^2 + \cdots + PE_i^n \times Em_p^n) \qquad (3.38)$$

where

ES_i	=	Energy saving in year i for TV	(year)
Em_p^n	=	Emission p for fuel type n for unit electricity generation	(kg/kWh)
ER_i	=	Emission reduction in year i of TV	(kg)
PE_i^n	=	Percentage of electricity generation in year i for fuel type n	(%)

3.11 Prediction of market transformation

The purpose of predicting market transformation is to graphically indicate the shift of the present average efficiency towards the efficiency when the 10% standard and the energy label program are enacted. In this study, a bell curve is used to indicate this transformation.

With the implementation of energy efficiency standard, the market transformation will force the average efficiency of the appliance from the first curve (present average efficiency) towards the second curve (standard average efficiency). It is expected that the transformation will follow similar path as Figure 3.3.

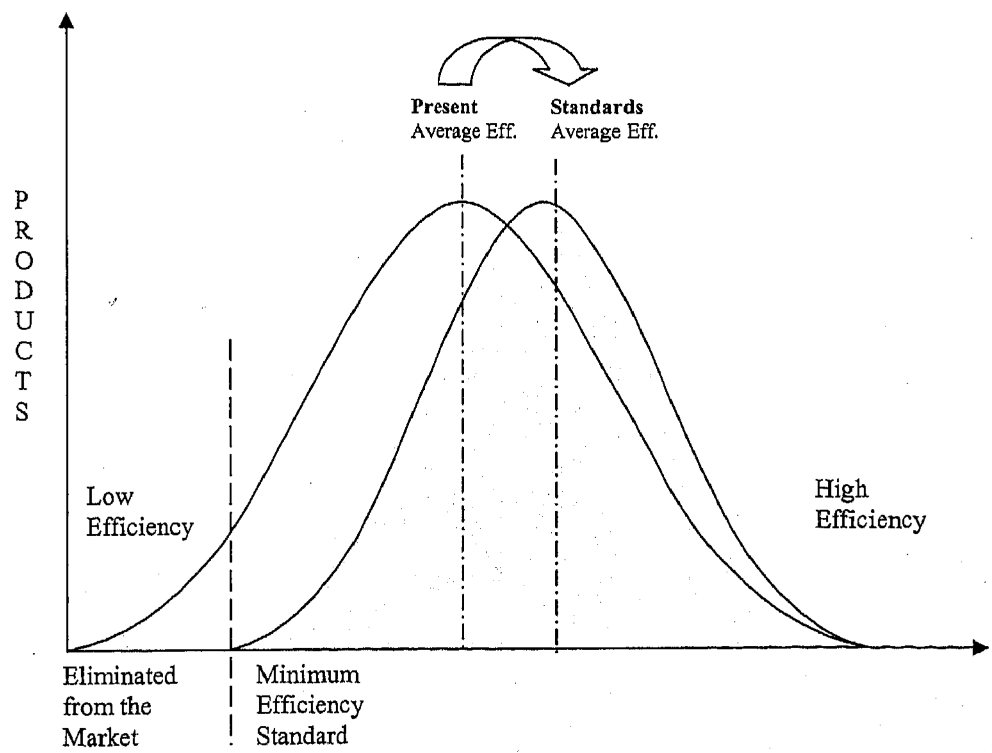

Figure 3.3 Market transformation due to standard implementation (Mahlia, 2002)

Additionally with the introduction of energy label, it is expected that consumers will purchase more efficient models from the market. This will eventually increase the penetration of more efficient models in the marketplace. As a result, the market transformation will force the average efficiency of the appliance from the second curve (Figure 3.3) towards the third curve (Label average efficiency). The market transformation due to energy label implementation is presented in Figure 3.4.

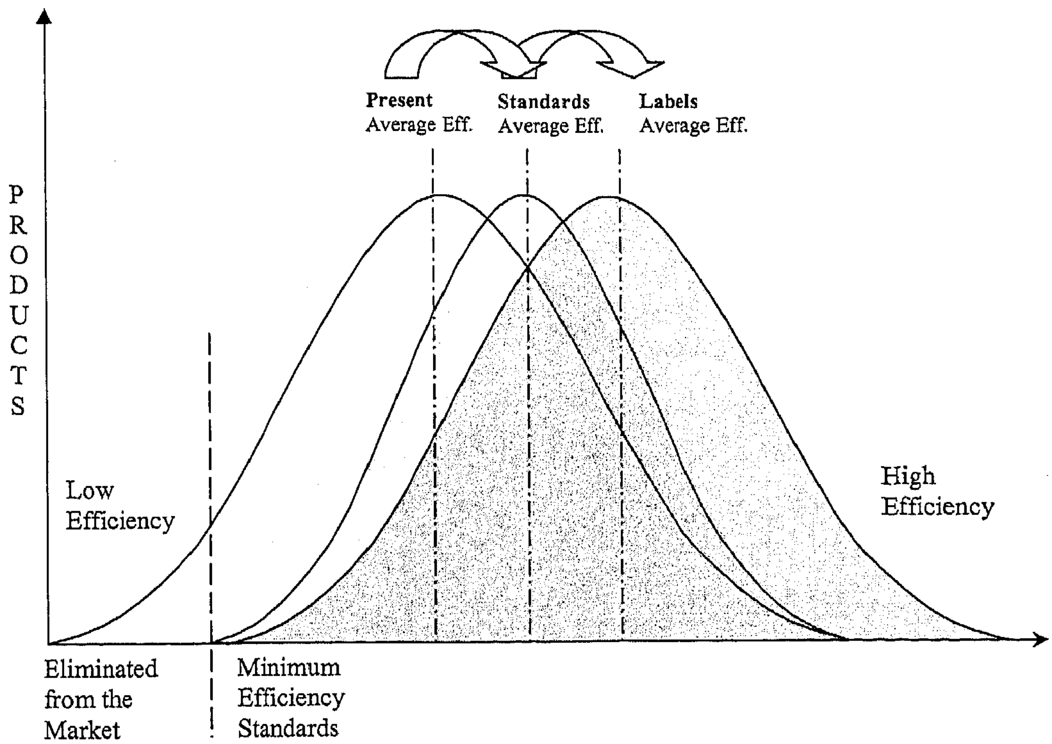

Figure 3.4 Market transformation due to standard and label implementation

(Mahlia, 2002)