CIB.86

Advancing Building Technology

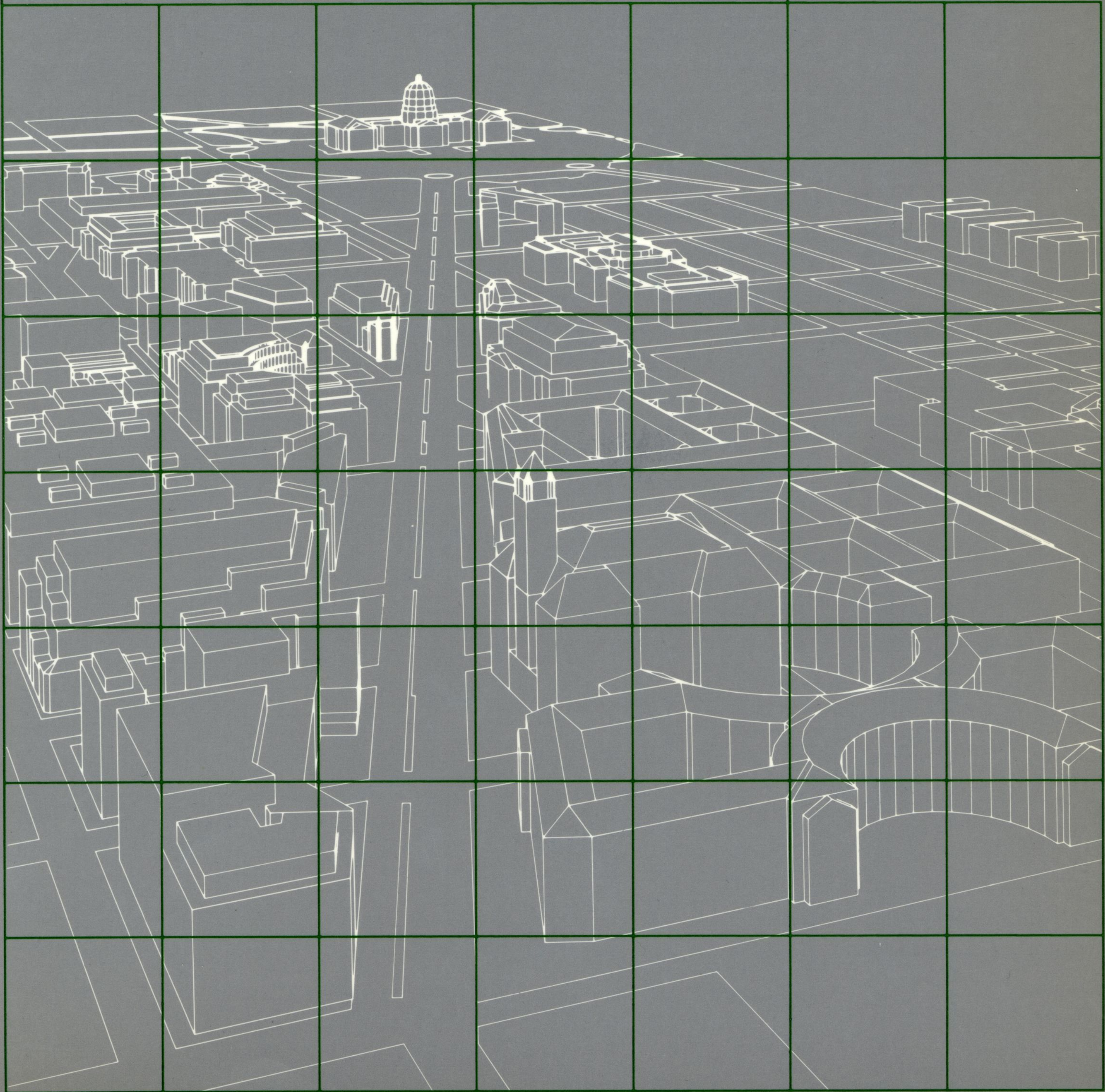
Proceedings of the 10th Triennial Congress of the
International Council for Building Research, Studies and Documentation

September 22-26, 1986
Washington, D.C., USA

Volume 9

Translating Research Into Practice

Sessions 7 and 8



Renovation of dwellings - life-cycle costs

Stig-Inge Gustafsson, Björn G Karlsson, and Bertil H Sjöholm

Linköping Institute of Technology
Department of Mechanical Engineering
Division of Energy System
S-581 83 Linköping, Sweden

KEYWORDS

Building, Energy Conservation, Installations, Life-cycle-cost, Optimization, Renovation.

ABSTRACT

Renovation of dwellings are mostly done without closer studies of the total costs (capital and running costs, including energy). Minimization of the total sum of the costs during the life-time of the buildings will give several benefits both to the society and the houseowners. This paper describes a mathematical model of the building as an energy system. House specific parameters, costs and climate data are inputs to the model. Time-of-use rates have been tested for both electrical and district heating systems. (Cost accurate conditions as economical system boundaries.) There are two principal solutions to the model that have been minimized as regards lifetime costs of the house. Either the efforts should be concentrated on the heating conversion system (efficiency) in the house or on a lower energy use in the building (conservation). The choice depends on the quality for each house.

Renouvellement des batiments - frais pendant la duree de la vie

Stig-Inge Gustafsson, Björn G Karlsson, and Bertil H Sjöholm

Linköping Institute of Technology
Department of Mechanical Engineering
Division of Energy Systems
S-581 83 Linköping, Sweden

MOTS-CLES

Renouvellements, Batiments, Conservation de l´energie, Frais, Systemes d´energi.

SOMMAIRE

Le renouvellement des batiments est souvent fait sans qu´on en ait etudie les frais totaux (des frais de capital et les frais d´exploitation, de l´energie incluse). Une reduction maximale des frais pendant la duree de la vie des batiments donnera plusieurs avantages a la societe et aux pro prietaires. Ce papier decrit un modele mathematique d´un batiment comme un systeme energique. Inclus dans le modele est les parametres specifiques pour des batiments, des frais et les renseignements climatiques. Des tarifs differenties a l´egard des saisons ont ete eprouves, et dans un systeme chauffage urbain. (Des tarif frais reels comme des limites des systemes economiques.) Il y a deux solutions principales du modele, a l´egard de la duree de la vie du batiment. Ou les efforts s´orienteront vers le systeme de transformation du chauffage (vers l´efficacite) dans le batiment, ou ils s´orienteront vers une consommation d´energie plus basse (vers economie d´energie). Le choix depend de la condition de chaque batiment. Ce modele contribute a creer une methode plus facile pour trouver des frais minimums dans des circonstances differentes. Il montre aussi quelles seront les consequences pour chaque proprietaire. (La solution economique la plus efficace.),

Introduction

A building can be imagined as an energy system. The system, during steady-state conditions, can be calculated by using a simple power equation that relates the power supply to the power losses.

$$P\cdot\bar{f}+P_{free}=\sum \bar{U}_i\cdot\bar{A}_i(\bar{T}_i-T_o)+\bar{M}\cdot C_{pa}(\bar{T}_i-T_o)+\bar{V}\cdot C_{pw}\cdot\overline{\Delta T}$$

As shown above there are only 8 parameters, notified with a stoke, that can be varied (Ref 1). When renovating dwellings there is an opportunity to change those parameters in order to minimize the life-cycle cost. This means that the sum of the building cost, maintenance cost and running cost, shall be as low as possible. We have designed a mathematical model of a simplified building, which can easily be modified in order to examine the variation in the life-cycle cost.

Mathematical model

$C_{B,C}=(a+b+c\cdot t_i)A_i$ (1) $C_{B,I}=g+h\cdot P_{new}$ (2)

$P_{new}=(\sum A_i\cdot U_{i,new})\cdot(T_i-T_o)$ (3) $C_M=0.02\cdot C_{B,I}$ (4)

$C_R=e\cdot f\cdot d\cdot\sum(A_i\cdot U_{i,new})$ (5)

$U_{i,new}=(l_{i,new}\cdot U_i)/(l_{i,new}+U_i\cdot t_i)$ (6) $PV_{single}=(1+R_r)^{-m}\cdot B$ (7)

$PV_{annual}=(1-(1+R_r)^{-n})/R_r)\cdot C$ (8) $R_r=(r-q)/(1+q)$ (9)

where

a = the cost for inevitable renovation, SEK/m^2
A_i = the surface area of the part "i", m^2
b = the immediate cost for starting the extra insulation, SEK/m^2
B = the cost for a single payment, SEK
c = the cost for insulation per meter thickness, SEK/m^2,m
c_{pa}, c_{pw} = specific heat for air and water
C = the annual cost, SEK/year
$C_{B,C}$ = building cost for the climate shield, SEK/year
$C_{B,I}$ = building cost for the heating equipment, SEK
C_M = maintenance cost, annual, SEK/year
C_R = running cost annual, SEK/year
d = the number of degree hours for the locality, $^oC\cdot h$
e = cost for energy, SEK/kWh
f = efficiency (dimensionless)
g = the immediate cost for changing the heating equipment, SEK
h = the cost per unit of power in the heating equipment, SEK/kW
$l_{i,new}$ = the thermal conductivity for the new insulation in part "i", W/^{o}C,m
m = the time from the present to when the cost appears, years
M = net ventilation flow, m^3/h
n = life-cycle time or optimization time, years
p = power, kW
P_{free} = free power from various sources e g sun, electric

ovens etc, kW

P_{new} = the power of the new heating equipment, kW

PV_{single} = present value for a single occasion, SEK

PV_{annual} = present value for annual costs, SEK

q = annual increase in costs for energy (dimensionless)

r = rate of interest (dimensionless)

R_r = the calculated rate of interest (dimensionless)

t_i = the thickness of the insulation at part "i", m

T_i = the inside air temperature, ^oC

T_o = the outside air temperature, ^oC

U_i = the existent thermal transmittance for part "i", $W/^oC,m^2$

$U_{i,new}$ = the new thermal transmittance (after the extra insulation)

V = tap water flow, m^3/h

ΔT = temperature rising of tap water, ^oC

Considering the formulas (1) - (9) above, we see that this simplified house consists of the climatic shield and the heating equipment. (In this paper we don´t calculate on the variation in the tapwater and the ventilation flow.)

Calculations

With the use of pricelists for the heating system, building cost, with information on wages, time for dismantlement and installation and use of the actual figures for the climate, (Ref 2), we can find the present value of the total costs for an existing house, PV_E. By the use of (6) and (1) we can also, in the same way, calculate an expression for the present value for the extra insulated house. This expression has the form

$$PV_{new}=C_1+A_i \cdot c \cdot t_i+(C_2/(l_{i,new}+u_i \cdot t_i)) \qquad (10)$$

where C_1 and C_2 are constants. The minimum of PV_{new} will occur when $t_{i,opt} = -(l_{i,new}/u_i) + (C_2/(c \cdot U_i))$ (11)

After this we can easily calculate PV_{new}. Only if $PV_{new} - PV_E < 0$ is it profitable to do anything to the house in order to lower its energy costs.

Numerical example

For an external wall, common in Swedish houses from 1940 and earlier, we have calculated with the following values

$a = 325$ $l_{i,new} = 0.0475$ $e = 0.25$

$b = 85$ $m = 30$ (for the facade) $g = 7\ 500$

$c = 555$ $n = 50$ $h = 464$

$A_i = 1\ 000$ $r = 0.05$

$U_i = 1.06$ $q = 0.02$

The remaining lifetime for the existing facade has been assumed to ten years. The calculation results in $PV_E = 1\ 020\ 000$ SEK

$PV_{new}=520\ 800+555\ 000 \cdot t_i+(34\ 500/(0.0475+1.06 \cdot t_i))$

and the minimum for PV_{new} = 764 700 SEK will occur when t_i = = 0.197(m). $PV_{new} - PV_E < 0$ and therefore it is profitable to apply insulation to the wall.

Variations of the parameters

In the following pages we show how a change in one of the parameters above will influence on the optimal insulation thickness. All the other parameters are then kept constant.

Change in the building costs:

Looking at the expression (10) and (11) it is obvious that changes in the parameters "a" and "b" in (1) will not change the $t_{i,opt}$. However, these values are hidden in the constant C_1 (10) and they therefore influence PV_{new}, which means that PV_{new} can become greater than PV_E and the insulation maybe becomes unprofitable. A change in "a" also has an effect on PV_E and the difference in the building costs for the wall will, according to this, have a very small influence. In Fig 1 we see that a change in the insulation cost (c) will influence on $t_{i,opt}$. For "normal" values of "c", 300 - 600 (SEK/m^2,m), (Ref 2), the t_{opt} will be approximately 0.2 - 0.3 meter. For the interval showed in the graph, the present value for the existing house always is higher than for the insulated one. $PV_E > PV_{new}$ and insulation is therefore profitable.

Changes in the running costs:

Fig 2, shows how different energy prices will change the $t_{i,opt}$. Note! When the energy price is lower than 0.15 SEK/kWh the present value for the existing house is lower than for the insulated. In this situation it is more profitable not insulating at all. We also see that the limit for profitable insulation is about 0.12 (m).

Normal differences, 80 - 140 ($10^3 \cdot {}^oC$ h), in the climate has only a small influence on $t_{i,opt}$ (Ref 2). For these climate values it is also always profitable to insulate the wall. ($PV_E > PV_{new}$.) (Fig 3.)

The existing thermal transmittance is one of the most important parameters in the model, Fig 4. Walls which have better U-values than 0.6 (W/m^2 ^{o} C) are not profitable to insulate. Also very bad walls have a $t_{i,opt}$ about 0.2 m. The region for profitable insulation is about 5 cm ($0.17 < t_{i,opt} < 0.22$ m).

Changes in economical parameters:

For all the parameters considered in the graphs above it is possible to calculate with almost the true values. This is not the situation when you shall decide the levels for the economical parameters.

The graph, Fig 4, shows that insulation of the wall is not profitable when the optimization time is less than 15 years. Life-cycles longer than 50 years will influence very little on the optimal insulation, which varies between 0.12 and 0.20 (m). It is therefore not very important to find out the proper length of the life-cycle.

A change in the rate of interest, Fig 6, is very important to the result. Unfortunately it is not easy to find the accurate value for the rate, and in that way, $t_{i,opt}$. As shown in (9) the impact is similar for a change in the variation in energy prices (q). Rate of interest lower than 8 % makes insulation profitable. The fact that the inflation is excluded from the rate makes it plausible that it is adequate to set "r" to less than 8 %, at least in the state finances and then $t_{i,opt}$ will fall in the interval of about 0.15 - 0.25 m.

A change of the life-cycle for the facade (m) in (7) only will influence on C_1 in (10) and will therefore not change the $t_{i,opt}$.

As a result of this particular house, it is obvious that for reasonable ranges in the parameters, it should be appropriate with about 0.2 m extra insulation, when the $PV_{new} < PV_E$.

Changes in the heating system

As seen in (3) it is possible to change the heating equipment after having insulated the walls. For ordinary oil-boilers this does not change the present value for the house very much. Changing from oil to electricity, with its better efficiency, will give a lower present value if the optimization time is not to short. District heating, if it is available, has a low PV_{new} but only if a cost accurate rate is applied to the consumer (Ref 3). Ordinary rates for about 0.3 SEK/kWh will not have a big influence in the present value. In fact the short time marginal cost is much lower, about 0.1 SEK/kWh in the summer and 0.2 SEK/kWh in the winter (Ref 4). As seen from the graph for the energy price, Fig 2, the limit for profitable extra insulation has then already been reached. A heat pump, which can produce a lot of energy for a very cheap price/kWh, can sometimes be an alternative to insulation, but in our calculations the power cost (h) is so high that it is more profitable to insulate the walls. However, the lowest PV_{new} almost always seems to come from the electrically heated building with extra insulation.

Conclusions and further work

It seems that for houses with poor climate shields ($U_i > 0.6$ $W/m^2 \cdot {}^oC$) it will be profitable to insulate the wall. In our case the thickness of extra insulation shall be about 0.2 (m).

If the house has a better shield, it is not profitable to insulate. The energy consumption in the existing house is still very high, so it may be profitable to install a heatpump. If the shield is very good the energy-demand is too low for the heatpump to compete and then it is better not to do anything to the house. In our further work we are trying to minimize the life-cycle cost by the use of a non linear programming method. When this is done it shall be possible to find the optimal renovation strategy for each unique building.

REFERENCES

1. C. Björk, B. G. Karlsson, "Optimization of building construction with respect to life-cycle cost", Third International Symposium on Building Economics, Ottawa, 1984.

2. Different pricelists, e g "Rörgrossistföreningens prisbok 1985", which brings information of the cost for the heating equipment. Renovation of buildings 85/86, "Sektionsfakta ROT 85/86", Wikells byggberäkningar AB, (Sweden). Wages agreement and contracts for heating installations e g "Rörprislistan" and VVS-installationsavtalet 1985. Climate values from the Swedish Meteorological and Hydrological Institute, (Norrköping, Sweden).

3. B. H. Sjöholm, "Influence of Differential Rates on Heating Systems", Dissertations, no 119, Dept of Mechanical Engineering, Linköping University, (Linköping, Sweden, 1984).

4. S-I. Gustafsson, B. H. Sjöholm, B. G. Karlsson, "Differential rates for district heating - An analysis of consequences for renovation of dwellings, LiTH-IKP-R-412, (Institute of Technology, Linköping, Sweden, 1985), (in Swedish).

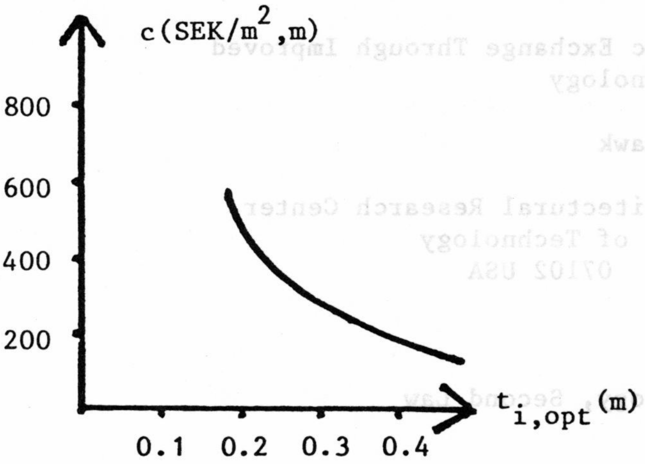


Figure 1. Changes in the insulation cost, c.

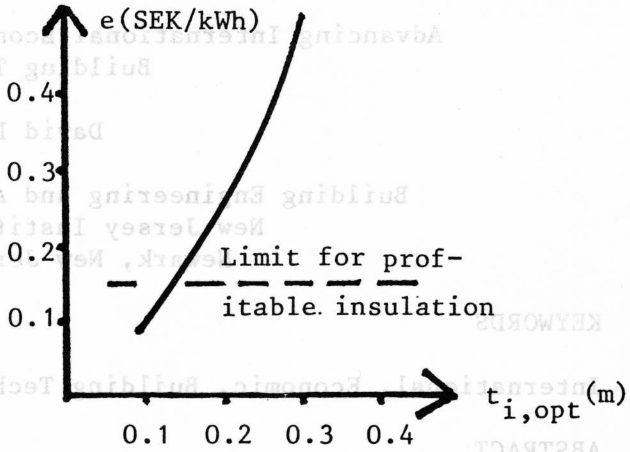


Figure 2. Changes in the energy prices, e.

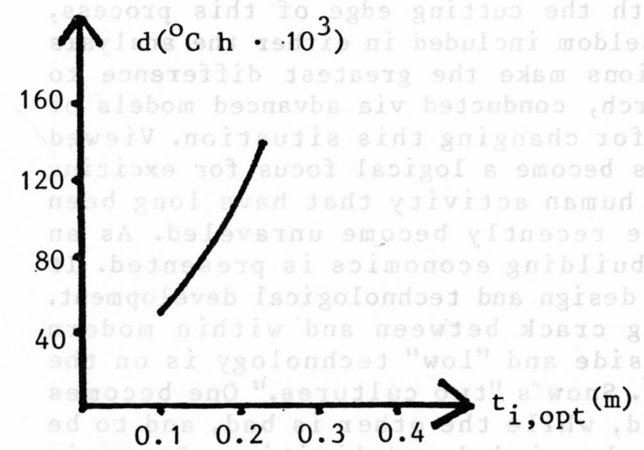


Figure 3. Changes in the climate, d.

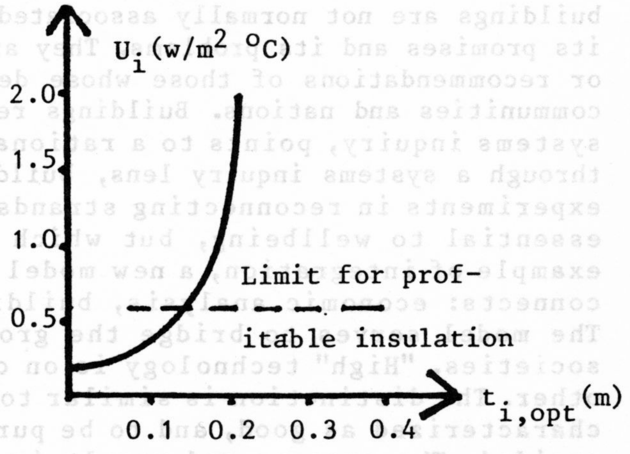


Figure 4. The influence of different thermal transmittance in the existing wall, U_i.

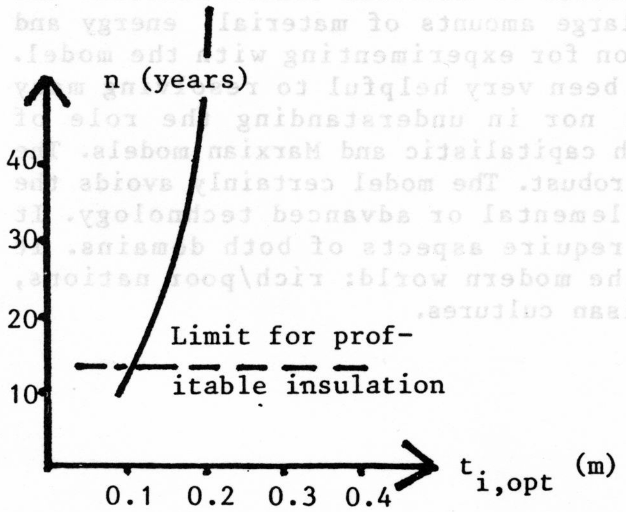


Figure 5. Changes in the optimization time, n.

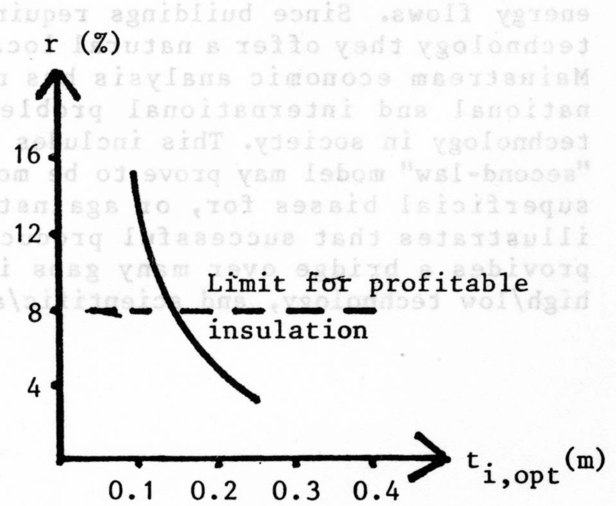


Figure 6. Changes in the discount rate, r.